GEOLOGICAL SURVEY OF OHIO

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J. A. BOWNOCKER, State Geologist

FOURTH SERIES, BULLETIN 11

THE MANUFACTURE OF ROOFING TILES

By WOLSEY GARNET WORCESTER

EDWARD ORTON, Jr., Collaborator and Editor

Published by authority of the Legislature of Ohio, under the supervision of the State Geologist

COLUMBUS, OHIO, AUGUST, 1910

Printed by the Springfield Publishing Company,
Springfield, Ohio.

GOVERNOR JUDSON HARMON:

My Dear Sir—I transmit herewith a bulletin on the Manufacture of Roofing Tiles by Wolsey Garnet Worcester with the co-operation of Professor Edward Orton, Jr. So far as I can learn this is the first bulletin prepared in any country on this subject.

Ohio is pre-eminent among the states in the clay industries, and it is fitting that she should lead in the scientific discussion of clays and the processes by which they are made of service to man. This is the first of a series of bulletins treating of these subjects, all of which will be under the general supervision of Professor Edward Orton, Jr.

Respectfully submitted,

J. A. BOWNOCKER,

State Geologist.

Columbus, Ohio, August 1, 1910.

THE SURVEY IN ITS RELATIONS TO THE PUBLIC.

The usefulness of the Survey is not limited to the preparation of formal reports on important topics. There is a constant and insistent desire on the part of the people to use it as a technical bureau for free advice in all matters affecting the geology or mineral industries of the State. A very considerable correspondence comes in, increasing rather than decreasing in amount, and asking specific and particular questions on points in local geology.

The volume of this correspondence has made it necessary to adopt a uniform method of dealing with these requests. Not all of them can be granted, but some can and should be answered. There is a certain element of justice in the people's demanding such information, from the fact that the geological reports issued in former years were not so distributed as to make them accessible to the average man or community today. The cases commonly covered by correspondence may be classified as follows:

1st. Requests for information covered by previous publications.—This is furnished where the time required for copying the answer is not too large. Where the portion desired cannot be copied, the enquirer is told in what volume and page it occurs and advised how to proceed to get access to a copy of the report.

2d. Requests for identification of minerals and fossils.—This is done, where possible. As a rule, the minerals and fossils are simple and familiar forms, which can be answered at once. In occasional cases, a critical knowledge is required and time for investigation is necessary. Each assistant is expected to co-operate with the State Geologist in answering inquiries concerning his field.

3rd. Requests from private individuals for analyses of minerals and ores, and tests to establish their commercial value.—Such requests are frequent. They cannot be granted, however, except in rare instances. Such work should be sent to a commercial chemical laboratory. The position has been taken that the Geological Survey is in no sense a chemical laboratory and testing station, to which the people may turn for free analytical work. Whatever work of this sort is done, is done on the initiative of the Survey and not at the solicitation of an interested party.

The greatest misapprehension in the public mind regarding the Survey is on this point. Requests for State aid in determining the value of private mineral resources, ranging from an assay worth a dollar, up to drilling a test well costing several thousand dollars, represent extreme cases. At present there is no warrant for the Survey making private tests, even where the applicant is entirely willing to pay for the service.

In many cases individuals would prefer the report of a State chemist or State geologist to that of any private expert, at equal cost, because of the prestige which such a report would carry. But it is a matter of doubt whether it will ever be the function of the Survey to enter into commercial work of this character; it certainly will not be unless explicit legal provisions for it are made.

4th. Requests from a number of persons representing a diversity of interests, who jointly ask the Survey to examine into and publicly report upon some matter of local public concern.—Such cases are not common. It is not always easy to determine whether such propositions are really actuated by public interest or not. Each case must be judged on its merits. The Survey will often be prevented from taking up such investigations by the lack of available funds, while otherwise the work would be attempted.

The reputed discovery of gold is one of the most prolific sources of such calls for State examination. It usually seems wise and proper to spend a small sum in preventing an unfounded rumor from gaining acceptance in the public mind, before it leads to large losses, and unnecessary excitement. The duty of dispelling illusions of this sort cannot be considered an agreeable part of the work of the Survey, but it is nevertheless of very direct benefit to the people of the State.

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[1] The sale edition of Bulletin 3 is exhausted.

FOURTH SERIES, BULLETIN 11

THE

MANUFACTURE OF ROOFING TILES

By

WOLSEY GARNET WORCESTER

EDWARD ORTON, Jr., Collaborator and Editor

AUGUST, 1910

LETTER OF TRANSMITTAL.

DR. J. A. BOWNOCKER, State Geologist:

Dear Sir—I take pleasure in handing you herewith the first one of a series of Bulletins on the Clays and Clay Products of Ohio. The subject of this bulletin is Roofing Tiles, and has been prepared under my general direction by Mr. Wolsey Garnet Worcester, Instructor in Ceramic Engineering in the Ohio State University, and formerly identified with the Roofing Tile industry as designer, builder and operator of roofing tile factories.

The manufacture of roofing tile is not one of the most extensive of the clay industries, either in Ohio or in the United States. The reason for its treatment in the first of the proposed series of Bulletins on the Clay industries, is that it is the first report to reach completion, out of several which are under preparation. As this report is practically an independent and complete treatise in itself, no adequate reason exists for delaying its appearance until other reports are ready.

It has been the aim in this report and in the others which are to follow on allied topics, to diverge quite widely from the type of reports formerly issued by this and most of the other states, in which the geology of the clay beds, their occurrence and extent, have been the matters of first importance and the technology of the clay industry has been generally lightly touched upon. It is my belief that of the clay beds of Ohio and their occurrence, and quality, enough has been said already by the reports of the Geological Survey to very fairly present this topic to the people of the State. But the utilization of clays of the types found in Ohio is a matter of very much more intricate nature than their geological occurrence, and in this subject no headway can be made to convert the clays into an asset of wealth, except through an understanding of the technological processes of manufacture and the physical and chemical principles on which these processes rest. These reports are therefore directed primarily towards enabling the people of the State to use the clay resources which are available, and are therefore primarily technologic, rather than geologic in character. Mr. Worcester is peculiarly competent to present to the public an article on the manufacture of roofing tiles, on account of his practical experience in this industry, and it is anticipated that the value of his contribution will speedily be recognized when the report reaches the producers and users of clay architectural materials.

Very Respectfully submitted,

EDWARD ORTON JR., E. M.

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CHAPTER I.

A BRIEF HISTORY OF ROOFING TILE MANUFACTURE AND USE.

General—The origin of roofing tile is shrouded in obscurity. It can, however, be traced back several centuries before Christ. Early in man's career, he doubtless lived in such caves and natural shelters as are found in a mountainous country, but, as he migrated from place to place, it would happen that natural shelters could not always be found. The impulse and suggestion for him to construct temporary caves, or shelters of slabs and pieces of rock, would be a perfectly natural one and doubtless has recurred many times in various places and peoples in the development of the human race. These early homes were no doubt covered with some sort of thatch or stone roofing material; in mountainous countries flat stones of flaggings would naturally be tried. Experience unquestionably soon taught these early home builders the value of a sloped roof over a flat one, in shedding the rains.

According to Morse[1], the antiquity of the sloping roof is hinted at in the finding of cinerary vessels in the form of huts, and, consequently, known as hut-urns. These have been found in Italy, Saxony and other parts of southern Europe. It is believed they were made before the age of iron.

The sloping roof must have preceded the roofing tile by many centuries. At the outset, bark, straw, thatch, rough stones and similar substances were used until better devices were made, which finally culminated in roofing tile of terra-cotta. The oldest known type of clay roofing tiles is, by far, the most common form in use in the world to-day.

Most natural stones crumble, and metals oxidize or rust, but hard burned clay wares are nearly imperishable to the influences of decay. Thus it happens that terra-cotta roofing tiles are often the only surviving relics of a prehistoric structure. The enduring nature of these objects may ultimately enable us to trace the paths followed by the tile-making races in their various migrations.

While the actual beginnings of roofing tiles are not known, it is probable that their use was known very early in Asia Minor, and certainly very early in China. From the high skill of the potters and the great

[1] Morse, E. S. "On the Older Forms of Terra-Cotta Roofing Tiles," Amer. Arch. and Building News [1892] vol. 35, p. 197, vol. 36, pp. 5, 24, 52. This article has been freely used in various parts of this chapter, for which due acknowledgment is hereby rendered.

antiquity of the fictile art in China, and the use of artistic roofing tiles in that country in buildings erected some centuries ago, one might easily be led to believe that it was in China that the use of roofing tile originated.

Graeber, in his memoir "Terra-kotten am Gieson," describes what he believes to be the earliest known terra-cotta roofing tile. These were found in the ruins of the Temple of Hera at Olympia, dating nearly a thousand years before Christ. This ancient tile consisted of two elements, a wide under piece (tegula) slightly curved, and a narrow, semi-cylindrical piece (imbrex) which was placed in an inverted position so as to cover the upturned edges of two adjacent tegulae. While the tiles from the Temple of Hera are probably as old as any authenticated instances elsewhere, it is not to be supposed that the Greeks sprang all at once from the thatched hut of the wild sheep-herder, up to the level indicated by this efficient system of tile roofing. It is known that the beginnings of their other arts, pottery making, metal working, jewelry, sculptures, etc., were imported from older civilizations in Asia Minor, or elsewhere, and that while the genius of the Greeks soon developed all of these arts to a plane never before known in the world, they cannot be credited with their first discovery.

Fig. 1—Tiles from the Temple of Hera.

Among the substances used in the construction of early roofs, worked marble tiles, modeled after the terra-cotta tiles, were made some 650 years before Christ.

Throughout all parts of the old world can be found tiles or the fragments of them, proving to us that the use of tile has been universal there at one period or another.

The outline drawings[1] (Figure 2) represent in a general way the types and varieties of roofing tiles with their age and distribution.

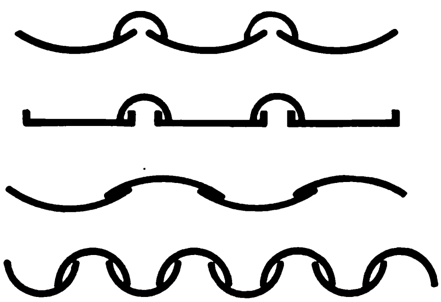

Fig. 2

It should be understood that colonies, past and present, usually adhere to the form of roofing tile in use in their parent countries. As

[1] After Morse, On the Older Forms of Terra Cotta Roofing Tile, Amer. Archt. and Building News, (1892), Vol. 35, p. 198.

an illustration,[1] flat tile made in Montgomery County, Pennsylvania. about 1735, can be traced to the old German settlers. At Bethlehem, Pennsylvania, the Moravians were making tile as early as 1740.[2] The pan tile discovered by Dr. C. C. Abbott[3] on Burlington Island, in the Delaware River, on the site of a very old house, said to have been built in 1668 by Peter Jagon, points clearly to the Dutch settler as its author. In California and Mexico, the normal or half round tile used in the missions were made by the early Spanish conquerors.

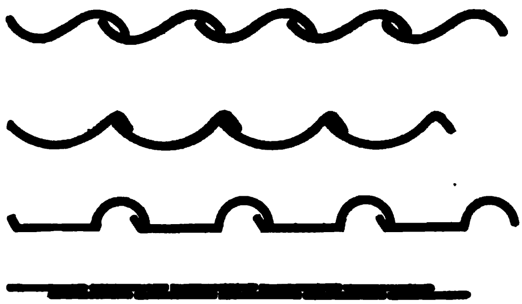

Fig. 2—Continued.

The tiles found in the above described localities are believed to represent the first use of roofing tiles in this country. It is quite possible that some of the first tiles used were brought from home by the colonists from their respective countries.

Ohio—Taking up the history of roofing tile in Ohio, it has been found a problem of less magnitude to trace their development.

On a branch of the Cincinnati Northern Railway, some thirty miles to the northeast of Cincinnati, is found the quaint old village of Germantown, which the records seem to indicate as the site of the first roofing tile manufacture and use in Ohio.

During the year of 1814,[4] Mr. Philip Gunckel laid out the village, and named it after Germantown, a suburb of Philadelphia, which still retains that title. About this time a Mr. John Robinson cast his lot with the early settlers of the little town, and began the manufacture of brick from clay gathered in a nearby field. Wishing to build for himself a home that would outdo those of his pioneer neighbors, Mr. Robinson made clay roofing tiles in quantity sufficient to cover his home and stable. Figure 3 shows very clearly the form and outline of the tile made by Mr. Robinson. These tiles were no doubt made from the same clay, and burned in the same kilns, as the brick which Mr. Robinson manufactured. The house has long since been destroyed, but the old stable withstood the ravages of time and storm until 1907. It was razed to make way for

[1] Barber, E. A. Pottery and Porcelain of United States, p. 51.
[2] *loc. cit.*
[3] *loc. cit.*
[4] Howe's History of Ohio, Vol. 2, p. 301.

a fine library building. The photograph shown in Figure 4 was taken just before the work of destroying the old building was begun.

The view of the stable shows the roof in a dilapidated condition, not from the failure of the tiles or brick in the structure, but from the rotting of the wooden beams and rafters, so that they could no longer carry their load.

Fig. 3—Robinson's Tile, made at Germantown, Ohio, about 1814.

To the right in the picture stands a corner of the new library building, upon which can be seen roofing tiles of modern manufacture. A more striking contrast could scarcely have been found, the one tile showing the marks of time and the primitive methods of manufacture of a century ago, while the other presents a roof of the present day.

The Robinson tile at Germantown was probably a sporadic case only, and does not probably stand for the introduction of the industry, as we have no evidence that he manufactured tiles for other than his own needs.

Unquestionably, the next step in the production of roofing tile in Ohio was taken by the Zoarites, a German religious sect, who settled in Tuscarawas County about 1820, and built a town which they called Zoar. The manufacture of roofing tile by these people was upon a much larger scale than the early efforts of Mr. Robinson at Germantown, as practically all of their buildings were tiled. One only has to look upon the many old roofs that can still be seen standing today at Zoar, to

recognize that the use of roofing tiles was not new to the people of Zoar. They came from a country where tiles had been used for centuries before they sailed away to build their Utopia in the wilderness, where they could be free to follow their own beliefs. The Zoar community has disbanded after a communal existence of about eighty years, but their honest workmanship and care have left buildings and roofs which will last for many decades to come.

Fig. 4—Building covered about 1814 with Tiles made at Germantown, Ohio.

These Zoar tiles are shingle tiles of the pattern known as the "Beaver Tail," the outline and style of which can be traced back to their native town, Wurtemburg. The tiles were all hand made; the clay was dug in the nearby fields, hauled to the tile yards by oxen, dumped into soak-pits, where water was added and the clay allowed to stand till soft. After soaking for a day and night, men tramped the clay with their bare feet until it was properly kneaded or pugged. It was then covered over with straw, weighted with rails or boards, thus keeping the clay plastic until needed by the molders. It was then spaded out, and carried by hand to the small workbenches of the molders. Wooden molds were used, which were previously wet and then sprinkled with sand. The molder first took up a lump of clay, which he rolled into a long tapered roll,

similar in shape to a loaf of rye bread. This roll of clay was then thrown or slammed forcibly into the center of the mold, and the molder, using his forearm and hand, would hammer or manipulate the clay until it completely filled the mold. The excess clay was then scraped off with a straight edged stick. Ordinarily the tile would have been considered complete at this point, but by observing the tiles shown in the illustrations, it can be seen that their faces have been grooved with gutters, or lines running lengthwise of the tile. These grooves were produced by the fingers of the workmen, each finishing his tile with lines that seemed most appropriate to him.

Fig. 5—Roofing Tiles made by the Zoar Community.

A two-fold purpose was filled by these grooves: first, they broke the monotony of the otherwise plain tile, and secondly, they furnished a means of keeping the rain water away from the lateral joints.

The tiles were carried from the molding benches by boys, to drying racks or floors, where they were emptied out from the molds and left to dry. The mold was carried back to the work bench, where it was first dipped in water and then sprinkled with sand, in readiness for another operation.

The burning was carried on in up-draft kilns similar to the up-draft clamp kilns used by manufacturers of soft mud bricks at the present time.

Tile manufacture was carried on by these quaint people until about 1852, when it was discontinued. As at Germantown, the tiles made at Zoar were not designed for commercial purposes, but merely to be used on the mills, store houses, shops, houses and barns of the Zoar community, amounting in all to a considerable number of structures.

The next step in the evolution of the manufacture of roofing tile in Ohio and probably the earliest establishment of the industry on a commercial basis in the United States, came during the year 1871, when Mr. J. B. Hughes of Terre Haute, Indiana, received letters patent on roofing tile of interlocking design, and at the same time on a machine to make such tiles.

Fig. 6—Old Church at Zoar, Ohio.

Among the first to become interested in the Hughes tile, was John W. Conrade of Zanesville, Ohio, who during the year 1873 purchased the right to manufacture the Hughes tile. Mr. Conrade opened a small plant during the fall of the same year and carried on the manufacture of the tile during the following winter. No roofs were covered, however, until the spring of 1874, when the residence of Mr. A. H. Watts in Zanesville was constructed with this tile. The Conrade factory did not continue long in operation.

Closely following the starting of the Conrade plant at Zanesville, Mr. Edwin Bennett at Baltimore, Maryland, embarked in roofing tile manufacture. In the beginning, the Bennett plant was also operated under the Hughes patents. Mr. Bennett was without doubt the second man in this country to take up the manufacture of roofing tile on a commercial scale. His plant was opened in 1876 and was in continuous operation up until the summer of 1908, when, owing to the death of Mr. Bennett, operations were stopped and it has since been dismantled.

Arriving in this country in 1841 from Woodville, Derbyshire, England, Mr. Bennett[1] joined his brother James Bennett at East Liver-

[1] Barber, E. A., Pottery and Porcelain of the United States, p. 192.

pool, Ohio, in a small pottery works which had been started in 1839 at that point, and which was undoubtedly the first pottery to be built at East Liverpool, and the foundation of the enormous industry which has developed there.

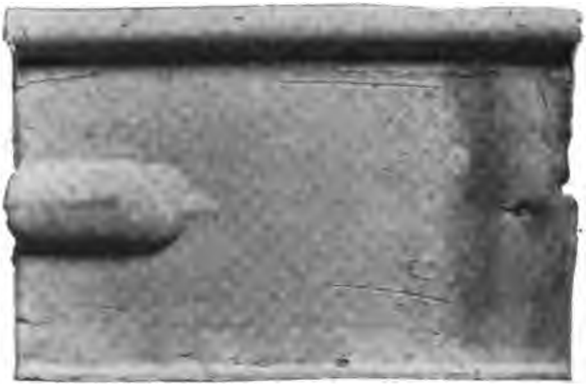

Fig. 7—Conrade Tile Taken from the Watts Residence, Zanesville, Ohio.

During 1846 Mr. Edwin Bennett severed his connection at East Liverpool, and moved to Baltimore, where he founded a whiteware pottery which is still in successful operation to-day. But, becoming interested in roofing tile in 1876, he embarked in the business in a small way. His entrance into this field was interesting, in that it marked a line of growth very unusual at that time and still so. The English potter as a rule has great pride in his craft, and a proportionate distaste for the other branches of clay manufacture, especially bricks and tiles, which he regards as on an entirely different plane from his own. But Mr. Bennett's vision was prophetic, in that he saw the ultimate importance of roofing tiles and the certainty of their use in enormous quantities, and he decided to apply his knowledge of clay manufacture to this new line. Unfortunately his efforts were largely premature, as the markets had not been at all educated to the use of tiles.

A year or so later, in 1877-78, Mr. Harris B. Camp at Cuyahoga Falls, Ohio, entered upon roofing tile manufacture.

Mr. Camp had a most interesting personality. He owned a factory for the manufacture of sewer pipes and hollow goods, and also a machine shop of considerable size, where he did a custom trade as well as building and repairing his own clay machinery. He was an inventive genius of a high order, but of the rare type that makes his ideas pay. He experimented continually, seldom doing the same thing twice alike, even when successful. He became very wealthy before his death. Mr. Camp's efforts in the roofing tile field were directed to the manufacture of the well known

diamond shaped pattern, invented by Courtois in France prior to 1856. He only continued a short time in this branch of clay manufacture, when he sold his interests to Mr. J. C. Ewart of Akron, Ohio.

Mr. Ewart took up the work with much faith and energy, and has unquestionably done as much or more than any other man to promote the use of roofing tile in the United States. The plant which he built at Akron in the late seventies was strengthened step by step and for many years held the record of being the largest and practically the only successful plant of its kind in this country, as the Bennett plant did not at any time assume large proportions, and was not largely known in the trade. Mr. Ewart's success in his business was due entirely to his energy and application. He accomplished what he did almost entirely by his own efforts, relying very little on exchanging ideas with other clay workers. He solved his own problems in his own way, and did this at a time before clay working had begun its modern expansion and control along chemical and mechanical lines. His methods, and especially his exclusiveness, did not enable him to retain the control of the business which he had by great labor secured. Opposition began to develop, and ultimately his position became difficult. He finally withdrew from the business a few years ago, the plant being taken over by the present firm, The Akron Vitrified Roofing Tile Co.

It was not until a number of years after the starting of the Akron plant, that the roofing tile business was taken up by other manufacturers throughout the state. Among them was The Repp Roofing Tile Co., New Philadelphia, Ohio, about 1893; The Barnard Tile Co., Bellaire, Ohio in 1893; Zanesville Roofing Tile Co., at Zanesville, Ohio, in 1895; another one at Ottawa, Ohio, in 1900. None of the above plants operated to exceed three or four years at the longest, and none were successful in founding successful industries. About the same time, i. e., in 1895, a plant known as the Cincinnati Roofing Tile and Terra Cotta Co. was started at Winton Place, near Cincinnati, by Mr. Jacob Freund, inspired, as many of our German citizens are, with a true love and appreciation of a good tile roof.

Starting in a very modest way, this plant was built up step by step by its founder and associates. The problems of manufacture here were studied independently and met in their own way, as in the Akron plant, and while the product was of different shape and design, the business became slowly successful. It was founded on solid experience at every step of the way, and succeeded where the other plants of its own age failed, chiefly because it was not a copy of any other plant and because it evolved its own methods.

In 1902 a roofing tile plant at New Lexington, Ohio, was erected by a company of which Mr. A. W. Brown was President. This plant, at the time of its building, was designed upon broad lines, with ample

provisions for enlargement, and, in its short career of eight years, has developed into the next to the largest, if not the largest, roofing tile plant in the United States.

Following the New Lexington plant was one at Lima, Ohio, The National Roofing Tile Co., built by Mr. A. B. Klay, a native of Switzerland. Having been born and reared in a country where tile roofs have been the main reliance for centuries, it was only natural that Mr. Klay should see the great possibilities for roofing tile in this country.

Since gathering the field notes for this report, during the summer of 1908, a company has been formed at Canton, to build a plant at Sparta, Ohio, to manufacture dry-pressed roofing tile.

Other States—Considering the establishment of plants outside of Ohio, the Mitchell Clay Co.[1] during the year 1866 undertook the manufacture of roofing tile at St. Louis. They were, however, in advance of the times and after a period of about five years they discontinued the manufacture of this line of goods.

Other attempts were made at several points throughout the country, none of which met with success until the starting of the Celadon Terra Cotta Co., of Alfred, New York, built in 1888 by Mr. Geo. Babcock. This plant was one of the pioneers, and has been in continuous operation from the time of its building. At present it is one of the plants owned by the Ludowici Celadon Co., of Chicago, Ill.[2] During 1890 a plant for the manufacture of roofing tile was built at Ottawa, Ill., and known as the Chicago Terra Cotta Roofing and Siding Tile Co. It was operated by various owners for about twelve years and then was dismantled.

About 1893 the Ludowici Roofing Tile Company was formed in this country and built a plant at Chicago Heights, Illinois. This plant has grown steadily from the start until today it ranks among the largest.

The next plants of importance were the Standard Roofing Tile Company, St. Louis, built in 1895, and the Ohio Valley Clay Shingle Company, now the Huntington Roofing Tile Company of Huntington, West Virginia, built in 1899. During the following year, 1900, the Ludowici Roofing Tile Company built a plant at Liberty City (now Ludowici) Georgia.

It was not until three years later that other plants were built. During the year of 1903 there were three plants built, The United States Roofing Tile Company, Parkersburgh, West Virginia, The Mound City Roofing Tile Company, St. Louis, Missouri, and the Western Roofing Tile Company, Coffeyville, Kansas. The next year or during 1904, The Murray Roofing Tile Company was built at Cloverport, Kentucky; following this company was the building of the Detroit Roofing Tile Company in 1906.

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[1]Wheeler, H. A., Mo. Geol. Surv., Vol. XI, p. 436.

[2]Destroyed by fire in fall of 1909.

The latest company to enter the roofing tile field is the New York Roofing Tile Company at Saugerties, New York.

Other companies that are manufacturing or have manufactured roofing tiles, either alône or in connection with other clay products, are: The Alfred Clay Company, Alfred, New York; Burns and Russell, Baltimore, Maryland; Golden Press Brick Company, Golden, Colorado, Los Angeles Pressed Brick Company, Los Angeles, California; Gladding, McBean & Co., Lincoln, California; The Steiger Terra Cotta & Pottery Co., South San Francisco, California; N. Clark & Sons Co., Alameda, California; The Carnegie Brick & Pottery Co., Tesla, California; The Clay Shingle Company, Montezuma, Indiana; Spillman Brick Company, Spillman, West Virginia, and probably a number of others.

Status of Manufacture Outside of United States—Roofing tiles are now manufactured in all parts of the world occupied by civilized races. In the far East we find well established industries in China, Japan, Java, India and the islands of the Asiatic coast. The manufacture of tiles in these countries is possibly not as great at the present time, as it has been in the past, owing to the frequent relaying of the excellent tiles, made years ago by their ancestors, on modern structures.

It can be said of the Chinese, that they excel all other races in the world in their skill in the use of roofing tile. Estates and residences are generally bounded by high brick walls, crested with tiles, and even the most common country homes have at least a tile-covered gateway, while temples, shops, and all buildings of the better class are tile covered as a matter of course. Moreover, China, Korea and Japan have all treated the roofing tile in an artistic way approached by no other countries, excepting Greece and Italy.

Passing on to Persia, Egypt and the countries bordering on the south and east coasts of the Mediterranean Sea, we find that many tiles are still used, and that they retain for the most part the old normal pattern.

In Italy, Switzerland, Spain, Asia Minor, Austria, Norway, Sweden, Belgium and Holland are many thousands of tiled roofs, but these countries are not properly called large producers of roofing tiles. They do not manufacture many tiles in excess of those needed for domestic use. On the other hand, Germany, France and England are all large manufacturers of tiles. They annually produce many squares for export purposes to South Africa, South and Central America, and the West India Islands. Some few tiles are manufactured in these latter countries, but their supply is for the most part imported. At Maracaibo, Venezuela, there are two plants making tiles: The Eastern Brick and Roofing Tile Co., which has been in operation for the last fifteen years, producing roofing tile by means of a French hand-power press, and the Western Brick & Tile Co., using a similar equipment. The combined

output of these two plants is naturally small, and hence the bulk of the demand has to be met by importations.

At Montevideo, Uruguay, Mr. John W. O'Hara, U. S. Consul, reports that the majority of roofs in that country are flat, like floors, being paved or covered with flat tiles like the English "quarries," locally known as "baldosas." Many thousands of these are annually used, and he reports that in a single six months 2,537,000 were imported, largely from England.

A vast amount of business in these southern countries is yearly lost to the United States, due partly to the scarcity of roofing tile plants in this country, more especially on our southern, southeastern and southwestern sea board. At present we have only one plant in this vast territory, viz., at Ludowici, Georgia. This situation is also undoubtedly due in considerable part to our insufficient and irregular lines of communication with these countries. American ships are rare in those waters and the bulk of American exports to them go in foreign bottoms. Another cause is the lack of knowledge of our American producers as to what is wanted by these southern neighbors, and generally a tendency to impatience with their demands for special shapes and styles. The English and Germans have secured the trade, by finding out what the customs of the country require, and supplying it, while Americans have in some instances adopted a "take it or leave it" policy which is very unsuccessful in securing trade.

Some tiles are produced in Cuba and Mexico, but only in the slow and primitive manner brought in by the Spaniards three hundred years ago.

In Australia many tile plants have been put into operation by the English, German and French settlers.

Status of Manufacture in the United States.—While the first manufacturing of roofing tiles in this country has been shown in the preceding pages not to be of recent date, it is nevertheless a comparatively new industry here. We have been slow in taking up the use of roofing tiles for several reasons which are discussed in detail a little later. At present, however, American ingenuity in this field, as in many others, has triumphed over time and tradition. Although slow to enter this field, our progress since entering it has been rapid, and American tiles today have many points of excellence, and some of superiority. From the crude presses brought into this country from Germany, England and France, our inventors have developed new roofing tile machinery that leads the world in simplicity, strength and output. Many improvements in the materials of which dies are made, and also in the construction of dies, have been made in the past few years, until now the time honored plaster die is to be found in but few roofing tile plants. The chief objection to plaster dies has been that they must be renewed daily, owing

to the rapid rate at which the soft plaster surface wears away, leaving the tile made upon them with a very rough and uneven exterior, which catches dust and dirt, and soon presents anything but an attractive appearance. To overcome these objections, our manufacturers have employed dies made of such materials as cast iron, steel, brass, gun-metal, aluminium, and various alloys, all of which are being used with more or less success.

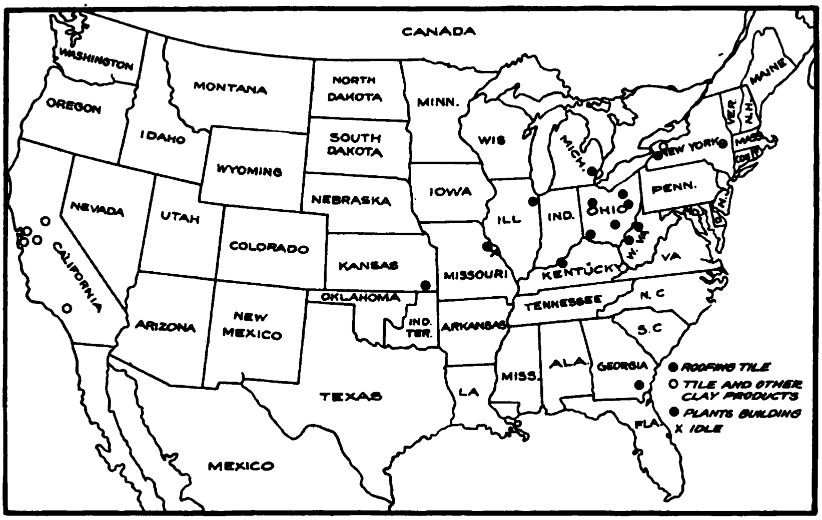

Fig. 8—Map of the United States, Showing Distribution of the Roofing Tile Plants.

In the past thirty years, the capacity of the roofing tile plants in this country has grown from the insignificant sum of from twenty-five to fifty squares per day, which is about the output of a single average plant, up to nine hundred or a thousand squares per day, if worked full time. In other words, the output has been increased from that of sufficient tile per day to cover a single medium sized building, to a number that would cover, roughly speaking, about twenty buildings of the same size.

It will be seen from Figure 8 that with two exceptions the plants are centrally located. It will also be observed that Ohio ranks first in the number of plants, with West Virginia and New York as second.

TABLE No. 1.

	No. Active Plants.	No. Building.	No. Idle.
Ohio	4	1	0
West Virginia	2	0	0
New York	2[1]	1	0
Illinois	1	0	0
Michigan	1	0	0
Kentucky	1	0	0
Missouri	1	0	1
Kansas	1	0	0
Georgia	1	0	0
California	4[2]	0	0

[1]One of these is in connection with dry press brick.
[2]All made in factories whose product covers a wide variety of clay wares. Roofing tile is not an important item in any of these plants, though made in all.

Ohio, at the present time, as always in the past, leads all other states in the production of roofing tile, as already shown. The first commercial roofing tile plant in this country was developed in Ohio, at Zanesville in 1873, and from the opening of the Zanesville plant, Ohio has, at no time, been without roofing tile industry, somewhere in her borders. Ohio manufacturers have generally kept abreast of the times, and have fought many of the hard battles necessarily encountered in the introduction of a new industry. In the face of the cheaper natural roofing materials, and also of the failure of some of the poorly made tiles and poorly laid tile roofs of early days, Ohio manufacturers have continually sought to produce more and better tiles, and to prove to the most exacting architect or builder that there is no other roofing material as nearly perfect as a well designed and well made roofing tile.

Approximately one-third of all the roofing tiles made in the United States are now produced in Ohio, and with the completion of the plant now in process of construction, the proportion will probably be raised somewhat higher.

Slow Development of the Industry in America.—Why have not tiles been used more extensively in the United States in view of their very extensive use abroad? There have been several conditions in the past which have greatly impeded the development of the industry. Some of these conditions still exist in some parts of the country. A discussion of these conditions will furnish an answer to the above question.

Firstly.—The competition of the wooden roof should be considered. The country is relatively new, and most of it originally abounded with magnificent forests of timber, suited for use as shingles. Cleared land was, and in some sections still is, at a premium, and any use to which the primeval forests could be put was gladly welcomed. While this surplusage of timber has now passed away forever in the east and central portions of the country, which are now beginning to feel the pinch of scarcity and to realize the awful wastefulness of the past, in some sections of the Northwest it is still possible to see enormous quantities

of wood ruthlessly burnt, in order to get rid of it. Thus for many years the use of other roofs than wooden slabs or shingles was very limited, owing to their cheapness and availability. As time passed and neighborhoods became towns, and towns cities, disastrous fires have occurred which have pointed out the importance of some more fire-proof roofing material, since the shingle-roofed house has formed a vulnerable point of attack in every large conflagration in this country, and in thousands of small fires. Thus the wooden roof, while still largely used, especially in the newer sections of the country, is doomed to a more and more rapid extinction, under the joint influences of increasing scantiness of wood supply, short life of wooden roofs under favorable conditions, and their constant danger of destruction by fire.

Secondly.—The competition of slate or natural stone. The conditions described as to the wooden roof have generally been first met by resort to slate, a natural stone of highly fissile character, capable of being readily sawed up into blocks of proper size, and split into very thin slabs of even thickness, which will stand further shaping and punching at the point of use.

The United States is fortunate in having a large natural endowment of slate, in widely distributed localities, and these quarries have been and will always be a source of much wealth to their communities. But slate is not free from faults, though it has many advantages which will always entitle it to an important place among roofing materials. It is cheap, easily applied, fireproof, and resistant to weather if of good quality. On the other hand, it is heavy, it is not resistant to weather if it contains soluble minerals, or easily oxidizable minerals like pyrites, or if it is not hard enough, i. e., too shaly. Also it is not very resistant to blows or strains, is not easy to repair when once laid in place, losses in shipping and application are rather high, and it makes a very plain, unornamental and uninteresting roof. The last reason is the most important of these, and were it not for this, slate would make the introduction of roofing tile a very slow and unprofitable venture. But slate only works in planes. It cannot be easily adjusted to curved surfaces, it possesses no relief, and makes a textureless roof and therefore one devoid of character, and its range of colors is limited to a small variety of blues, greens, browns and dull reds.

Thirdly.—The use of metal roofs, such as sheet iron, plain or coated with zinc or tin, and the use of corrugated or crimped or pressed iron plates has found a large field. The use of other sheet metals, such as pure zinc, copper or tin, is possible in some few cases, but in general is precluded by cost. The use of sheet iron in its various forms has the advantage of cheapness, non-combustibility, exceeding lightness, ready adaptability to any shaped structure, exceedingly rapid application, and easy repair, and easy preservation by paint applications. On the

other hand, it is very short lived unless thoroughly protected by paint or other applications at frequent intervals, and is thoroughly uninteresting in its appearance when finished, unless the pressing has gone to the extent of closely imitating roofing tile, in order to get the relief and texture. In this case, it is more costly than a metal roof ought to be, and has all the faults of any material which merely copies another.

The field of the sheet metal roof will therefore be likely to grow less rather than greater, and it will probably be confined more to factories, barns and low class sheds, and less to buildings with pretension to architectural merit.

Fourthly.—Composition roofs, made of sheets of artificial fabrics like paper, felt, asbestos, cloth, etc., water proofed with tar, asphalt, paint, and numerous patented and secret preparations, and covered with surface coatings of sand or gravel, are an important mode of covering cheap or temporary structures. Such roofs are largely confined to factories, flat roofed stores and store houses, and seldom applied to dwellings or important structures of any kind. However, they have the merit of cheapness, of water proof character to a very high degree even at low angles of pitch, of easy application and easy repair or removal. They lose their elasticity and crack and leak, if the filling material is allowed to dry out too long without renewal. They often are resistant to fire from the outside, though nearly always highly inflammable from within. The tar or asphalt roofs cannot be used on heavy slopes on account of drainage of the fluid during the summer heat. They are limited to strictly utilitarian purposes, having no pretensions to beauty under any circumstances.

Fifthly.—Cement roofing is a new factor in the market, which may be applied in two ways: 1st, as tiles made separately and subsequently applied and fastened in place, or 2nd, in sheets of reinforced concrete. Of the former, a comparison with clay roofing tiles will be made later. Of the latter, the strong points are its rigidity, its fire proof nature, its permanence when well made. Against it, lie the probability of bad workmanship (or the difficulty of securing good workmanship on which its duration and strength directly rest). Cement products in general are all open to this difficulty, that it is not easy to tell whether they are well made or not from their appearance, i. e., scanting in material or workmanship is exceedingly difficult to detect and where so much dependence must be placed on good faith, frequent abuses are always likely. Also, this style of roof is very heavy, and requires massive construction. Light or thin slabs are not satisfactory at all, as they crack if bent much or struck smartly.

Evidently, in competition with these five classes of roofing materials, most of them well entrenched in trade practice, roofing tiles have had to demonstrate their worth. Tile roofs have been unusual,

therefore not easily obtained and often causing long delays in completion of a building. They have been heavy, requiring strong construction and thus more costly. They have been poorly laid, by workmen unskilled in their use and oftentimes actually hostile to the new roof and glad to see it become unpopular on account of leaks or early repairs. They have been inherently more costly. But in spite of all these handicaps, and others not mentioned, the use of tile has increased more and more rapidly with each year. Its advantage in the hands of a skillful user, in the beauty of form, of surface texture, and of color, and its entire satisfactoriness when properly designed, made and laid, so far as weight and water-tight qualities are concerned, its uninflammable character and its actual resistance to the influence of exterior fire or water or both, its durability when properly designed and laid, all these and other advantages have been recognized by architects so thoroughly that now the great majority of large institutional buildings, fine residences, and others where architectural considerations have weight, use the tile roof. It has not yet invaded the field of the cheap roof, and it is by no means certain, under American conditions as to both labor and materials, that it ever will attain the wide usage which characterizes its use in Europe and in the Orient.

Handicaps—Some of the handicaps by which the use of roofing tiles has been limited in the past will, however, undoubtedly be removed as time goes on. In the *first* place, the design of a roofing tile, which can meet the exacting conditions of modern use, is becoming a less varied and more definite thing. Many fanciful, impractical and clumsy tiles have been "invented" or designed by various enthusiasts and their introduction has tended to hurt the cause and delay the use of the designs which are practical. Many of these theories have had to be tried out and lived down afterwards. Many of the leaky roofs and most of the slowness of tile roof construction has been due to poor design, part of it to poor workmanship. *Secondly.*—The weight of the early tile roof was excessive. Better machinery, better driers, better kilns, and more knowledge and experience on the part of the makers have overcome this objection in large part, and tile roofs are now furnished in which the weight consideration is no longer of much importance. *Thirdly*, the multiplication of plants will remove one of the biggest obstacles to the growth of the industry. With the avoidance of the excessive freight costs, and with the elimination of the delays caused by long shipments and frequently by congested factory conditions, there will come a great expansion in the use of tiles, not only from an economical standpoint, but from the side of artistic beauty, attainable by no other roofing material. With tile it is possible to get an everlasting roof in any pattern and of any desired color. The color is contained in a vitrified body, hence it is non-fading,

which is more than can be said of any other coloring compound used for any kind of a roof.

Cement Tiles—Within the last few years many patents have been taken out for cement roofing tile. Plants have been started here and there over the country from time to time, the greater majority of which have been failures. Several plants have started in Ohio, namely at Columbus, Lancaster and other points. Detroit, Michigan, also at one time had a cement tile plant. The trouble has been to produce a tile which is not too porous, and which would not crack from expansion and contraction on the roof. To overcome this, they have necessarily been made very heavy. A second strong objection has been the inability to get permanent colors. Although minerals and mineral oxides are used as colors, in the course of a single year they have been known to fade, presenting anything but an attractive appearance. Numerous roofs in Detroit covered with colored cement tiles are examples of this.

Asbestos Tiles.—A material lately come upon the market is a cement asbestos shingle or tile. This material is proving far better than the regular cement tile, on account of its extreme lightness and a certain amount of elasticity. The same objection can be made against this tile as against the regular cement tile, viz., it will prove very unsatisfactory when the question of color is considered. Furthermore, they have been known to warp badly, when exposed to the sun. To overcome this trouble a copper clamp or fastener has been devised and is being used on the later roofs of this material.

There undoubtedly will be a field for this material on large roofs of cheap construction, where extreme lightness is necessary, but for strictly first class and artistic work where something other than a flat or corrugated shingle is wanted, clay roofing tile will not likely be displaced.

Scanty Distribution of Roofing Tile Plants.—This question is perhaps the most important in connection with the promotion of the business. With at present only about one plant to three and one-half states, it is not remarkable that tiles are not more widely used. In many sections of the country a tile roof has never been seen. At the present time, not a single plant exists in our entire eastern coast region. In the entire South, only one plant can be mentioned, while the Southwest and West has not one single plant producing roofing tile as its sole output. In three or four plants in California, some few tiles are made in connection with other ware, but tiles form a minor part of the total output. When there are tile plants scattered through all the sections of our country, then we will begin to see the use of tile as a standard commodity, as bricks are used to-day. Nearly every town has its common brick yard, and nearly every state has one or more face or front brick plants, producing a high grade article, whose value will justify a freight rate to the large cities.

Thus should it be with roofing tiles. There is no present or future chance of shipping cheap tiles for covering barns and sheds. These should be made locally and carried in stock by dealers after the manner of the European countries. But the better class of tiles, such as Spanish, glazed and slipped, should be made by larger plants where proper material can be had, and shipped reasonable distances to their markets, as face brick and terra cotta are.

These conditions actually exist now, in respect to the character of plants that are now doing business. There are in practically every case well constructed and carefully operated factories, which reach their markets by long distance shipments almost exclusively. But in the furture, with three or four such plants in each of the well settled states to care for the finer trade, and with cheap tiles made in local yards for the cheaper trade, the industry will begin to compare with the development which it has reached in most other parts of the world.

From time to time statements are made in the clay trade journals by various writers, that the present day brick manufacturers should take up the manufacture of roofing tiles in connection with their present business. Such advice is extremely ill considered. The manufacture of roofing tiles is a business by itself and should receive the undivided attention of those in charge. The methods of drying, setting and burning are widely different from those of brick manufacture and attempts in the past to burn brick and tiles in the same kiln have proven in a large measure a failure. In addition, the practice is not economical. The tiles can be burned in a much shorter time than the brick, hence it is a waste of time and fuel to hold the tiles under fire, waiting for the brick to receive the necessary heat treatment.

There is no more reason for associating the manufacture of roofing tile with that of brick and drain tile, than for associating the manufacture of terra cotta with the same articles, or the manufacture of crude stoneware with fine porcelain.

CHAPTER II.

THE VARIETIES AND QUALITIES OF ROOFING TILES.

In making a critical analysis of the relative value of roofing tiles in comparison with other roofing materials, we see that in this country at least, the quality which enables this material to survive the attacks of competition and grow in spite of its greater cost, is its beauty, or the artistic quality which enables the architect to make the roof of a structure an ornament instead of a necessary disfigurement. The beauty of a roofing tile depends on two factors, viz., its shape or design and its color. Of the two, the design is more important, for with an uninteresting color (if not actually disagreeable) an attractive roof may be made if the design of the tile is cleverly handled, while with a poor design, even a tile of good color does not make an interesting roof.

But the possession of an artistic design alone is insufficient to justify the use of a tile roof. The properties of the material itself, its ability to resist weather, and its ability to resist the blows and accidental stresses of shipment, storage, application, and use, in short its strength, and also its weight in comparison with other roofs, all these must be considered. The qualities of a tile are therefore properly grouped along two lines, viz:

Artistic—design and color.

Practical or Utilitarian—durability, strength and weight.

GENERAL DISCUSSION OF VARIETIES.

The old adage, "There is no new thing under the sun," is as well exemplified in the design of roofing tile as elsewhere, for any critical examination of the tiles of the present day compared with those of ancient times shows at once that we are now merely ringing the changes on the same old fundamental shapes which man's brain evolved early in the world's history. We have, it is true, greatly modified and improved them in details, but we have not and cannot get away from the original type forms.

All roofing tiles may be divided into three great groups, viz:

1.—Shingles or Flat Tiles.

2.—Spanish or Normal Tiles.

3.—Interlocking Tiles.

Shingles or Flat Tiles—This pattern is the simplest of all; it is nothing more than a generally rectangular slab or plate of burnt clay,

about six inches wide and fifteen inches long, with holes punched at one end for securing it to the roof. In the eastern hemisphere, a lug or projection of clay is formed on the under side of the tile at the upper end, whereby it is hung on the roof purlin which supports it. Tile of this pattern make a very plain-looking roof. From a distance, the outlines of the individual tiles are lost, and the entire roof surface appears as though covered with a single coating of some red material. Upon drawing nearer to the building, the butt ends of the tiles form faint horizontal lines across the roof, but outside of these lines, very little else appears to break the monotony of the surface. To overcome this monotony, shingle tiles have been designed with quite strong vertical ridges and valleys, or the sides or edges of the tiles are made in a semicircle, so that when two tiles are placed side by side, a strong shadow line is thrown by the projection. Other patterns are also made, which have an increased thickness at the lower end over that of the upper, and in addition strong vertical ribs are added, thus making a much more impressive appearance. There are also numerous patterns of shingle tiles at the present time which have been made interlocking. All of these modifications tend either to break the monotony of the otherwise plain tiles, or to reduce the weight or number per square, or otherwise improve the roof.

The simple flat shingle when properly made, that is, straight and true, and when laid with the proper lap, makes a perfectly water-tight roof. Makers of other patterns often seek to discredit the shingle tile, by claiming that it is not water proof. It is true that a number of instances can be cited in this country in recent years where shingle-tiled roofs have failed to make a good water-proof covering. Upon a careful investigation of one of these unsatisfactory roofs, it was found that the tiles were very poorly made, being not only defective through side checks or cracks, i. e., checks extending in from the edges of the tile from one to three and one-half inches, but they were also very crooked, many of them being so warped that they were one-half inch or more out of true. In addition, they were very rough from careless handling while soft. Using tiles with the above defects, it would only be natural to expect the resultant roof to leak. The tiles described above were made about eighteen years ago, when the methods of manufacture were not well developed, and this particular roof happened to be the first contract taken by a company which was just beginning operations. Nevertheless it would have been possible to have sorted the tiles more closely, discarding the cracked and crooked ones, and thus have saved the roof from giving constant trouble for eighteen years, and its final replacement with other tiles. Shingle tiles as made today are greatly improved, and if properly laid should furnish a perfect roof.

The one great objection to the shingle tile design is its great weight,

which largely exceeds that of the other styles. While they are in the same class with a slate roof in weight, they weigh from 200 to 400 pounds per square (100 square feet) more than Spanish or interlocking tiles. They are also unpopular with roofers, from the fact that it takes so many tiles to cover a square (with ordinary sizes, about four hundred). To properly fasten these, the roofer must drive 800 nails, while with Spanish tiles about 160 cover a square, making only 320 or less nails to drive. It can thus readily be seen that it will require nearly twice as much time to lay a square of shingle tiles as it does for a similar area of Spanish tiles.

Architecturally, shingle tiles should be used on small structures only, owing to their being made in small units. Their size prohibits their use on large massive buildings, at least from an artistic point of view. For residences, park buildings, siding purposes, etc., where the roofs are not too elevated, shingle tiles make a very satisfactory covering.

The Old Spanish or Normal Tiles—This design has, without question, been used in more parts of the world than any other. While there are many modifications of the normal tile, from the simple half-round trough to the modern S tiles made on an auger machine, or the improved interlocking Spanish, they have no doubt all sprung from the ancient pattern such as we find used on the Temple of Hera in Greece about 1,000 years B. C.

To describe all of the many forms and modifications of the normal tile would be impossible and useless as well. The following notes will be restricted to the more important forms in use at the present time.

The real or typical normal tile is a trough shaped piece of clay ware of a more or less flattened semi-circular cross-section, enough smaller at one end so that the exterior of the small end will fit into the interior of the large end and thus provide for the necessary lap. The troughs are thus seen to be half sections of the frustrum of a cone of slight taper. The length varies from twelve to eighteen inches.

For the execution of certain styles of architecture, these half round pieces are placed on the roof so that one-half of the pieces act as covers for the other. That is, two rows of the half-rounds are carried up the roof inverted, or with the troughs up, and just far enough apart so that a single row, trough down, will interlock with the two inverted rows, thus forming a cover for their edges and the space between.

Another mode of using the typical normal shape is in connection with pan tiles, that is, flat tiles like shingles, but with the two edges turned up to form marginal ridges. When the half-round tile is laid in combination with the pan tile, the combination is known as the Roman design. While the original Spanish or normal tiles and the Roman designs are both manufactured at the present time, their use is ordinarily restricted in the United States to an occasional structure, where it is desired to

copy some ancient styles of architecture. For instance, there are many buildings in California and the southwestern United States, which are planned on the so called "Mission" type of architecture, which was the architecture introduced in that region by the Spanish padres who came up from Mexico, or from Spain direct, to establish their religion among the savage races who were then the sole occupants of that land. For these modern "Mission" buildings, modern tiles in the old Spanish designs are wanted, and in some instances, Mexican workmen are imported to make by hand and apply the crude Spanish tiles in the way that has been done for three hundred years in their own land, and thus give the roofs the characteristic texture and aged look which cannot be obtained with a machine-made product. For such purposes, the pure Spanish design is of course valuable, but when the questions of manufacture and use are considered, the old Spanish or normal tiles are not desirable, owing to the large number of pieces required to cover a square, and with the Roman style, it becomes necessary to maintain two sets of dies and pallets in order to provide the two forms required.

For severe northern climates, where rough winds are encountered, this kind of tile must be laid in an elastic roofing-cement to get a waterproof roof. As the tiles have no head and heel locks, and only overlap three inches, it becomes necessary to stop up this lap joint to prevent the wind from blowing the water up the joint between the two tiles and over the upper end of the lower tile, thus causing a leak.

The elastic cement mentioned is a compound consisting of some organic oil, with some mineral of red color, such as iron oxide or ore. This mixture is worked up to the consistency of soft putty and is applied in a thin layer, by a small trowel, to the upper end of the lower tile; then the overlapping end of the upper tile is bedded into it. Thus the two tiles are stuck or bound together, although there remains sufficient elasticity to permit of expansion and contraction of the roof. For this reason, a cement which sets or hardens, like plaster of Paris or Portland cement, cannot be used. The drying out or hardening of the elastic cement mentioned above is sure to occur in time, and when it occurs, it will crack under the strains brought about by changes of temperature and wind motions, and leaks begin to develop. Just what the life of these elastic cements is, has not been ascertained. One roof which had been on twelve years was examined by the writer and the cement was still plastic, and could be worked up into a paste between the thumb and finger. However, any design of roofing tile which depends on an elastic cement to make it a perfect roofing material is in default, because the life of the roof is that of the cement used, and relaying a roof is always an expensive and unsatisfactory task. Some tiles will always be broken in taking up and their color could not be matched in any new tiles, and the result would be

a patched appearance. This and the cost, which would be in excess of the original laying, on account of the cleaning of the old cement off before relaying could be done, makes it impractical to consider a method as commercially sound which calls for the use of an elastic cement.

Modern Spanish or S Tiles.—The difficulty of manufacture of a conical trough-shaped tile has made the use of the pure Spanish tiles an unusual thing, except in Mission architecture, as noted, but the beauty of the effects secured by their use is so great that there have been many efforts made to get a design which would avoid the tapering form, and still retain the same general effect. This has resulted in the development of the S tiles.

The S tile, as at present made, is in cross section the shape of a flattened letter S, laid with its vertical axis horizontal. In the true S tiles, each one consists of a parallel ridge and trough, but a modification is also in use, in which the trough is flat with an edge upturned vertically, while the ridge is curved in a half round as before. This shape is virtually a pan tile and Spanish tile in one piece, and does away with a part of the objection to the real pan tile. Both of these two styles fall under the general head of S tiles. In order to allow for the lap of the tiles, they are so made that the faces and backs of the tiles are of the same radial length. Thus they can be nested, one above the other, indefinitely.

These tiles, either the pure S tiles or the S pan tiles, have the same fault as the ones last described, viz, for ordinary roofs, it is necessary to use an elastic cement at the upper end of each piece at the point of overlap.

It has been the practice in many instances of late to lay roofs of these tiles dry, i: e., without cement. For roofs of any ordinary pitch, this practice is to be condemned, for in this case the roof must depend on the felt or building-paper, which is laid on the sheeting and under the tiles, to prevent wind suction. Also the tiles are nailed to the roof, and the felt paper is necessarily badly punctured, and is therefore not at all waterproof. Although no elastic cement will last indefinitely, it will at least for many years, and add very greatly to the value of the roof.

Although the auger machine S tile, or modern Spanish, has this one objectionable feature, it is nevertheless destined to be the form of Spanish the most largely used in the future, on account of its cost of production being lower than that of the press-made or interlocking Spanish tile, as it is run out in continuous bar form, and cut off in lengths. It can be sold cheaper than a pressed tile and will therefore be more widely used. From the architectural view point, the S tile is very good. Its strong vertical lines from eaves to ridge of a roof are suitable for buildings of magnitude and strong outline.

The Spanish design, either pure or in the modified forms, is the pattern that will be the most widely used in future work on the better

class of buildings, like churches, schools, libraries and institutions of all sorts, and possibly on large residences, but a sense of harmony prohibits the use of full-sized Spanish tiles on buildings of moderate size. Their extremely bold outlines and high relief makes an appearance of too much weight at the top of the building. This mistake is very commonly made at the present time by architects all over the country. It is largely due, no doubt, to the fact that the manufacturers are making but one size of Spanish or S tiles. However, when the time comes that our American architects more fully realize the artistic beauty of the tile roof, and perceive that this can only be developed by using tiles of proper proportion for the buildings on which they are to be used, there will be tile manufacturers ready to produce the desired varieties of sizes.

Interlocking Spanish Tiles.—Although it has been seen that the development of the S tiles has solved the problem of cheap and rapid manufacture, while still retaining much of the distinction, style and characteristic "texture" of the real or old Spanish tiles, it has failed to overcome this most serious defect, viz., the necessity for cemented joints to make the roof reliable in windy rain and snow storms. A further step has been taken in the interlocking Spanish design, to correct this deficiency. It may be objected that the use of the interlocking idea puts the tile out of the Spanish class altogether, but it does not seem so to the writer, for the name "interlocking tiles" has a distinct meaning in the trade and no tile maker or dealer would confuse an interlocking tile with an interlocking Spanish tile, if the terms were used in that way.. In any case, the interlocking Spanish tile is clearly distinct from the rest of the interlocking tiles and these latter will be discussed under a separate heading. This interlocking Spanish tile differs from the S tiles made on an auger machine very little in outline or appearance, but it is made with side and end locks, or tongues and grooves on the upper surface of the tiles, which intermesh with corresponding grooves and tongues on the lower surface of the contiguous tiles. By this device is produced a perfect tile, that is, one that will not need a cement to make it water-proof. With locks of proper height, and tiles that are properly made, it is possible to lay a roof of this design that will withstand any storm except such a one as would be in danger of lifting the roof itself.

The cost of producing this tile is naturally above that of the straight auger-machine S tile, since the locks can only be put on by pressure in a tight die, but the superiority which it undoubtedly affords should insure its use on the better class of buildings.

From an artistic point of view, the press-made Spanish tiles are much better than the flow-die pattern, inasmuch as it is possible to give the butt or lower edge of the tile a rounded or curved shape which agrees with the other curved lines of the tile and make the whole consistent, while in the auger-machine S tiles, the ends are wire-cut and stand out in a sharp, harsh line in marked contrast to the flowing curves of the roll of the tile.

Interlocking Tiles.—As explained in the preceding section, this tile, unqualified by any other word, is understood in the trade to mean a pressed tile of a shape different from Spanish or S tiles, and as the name implies, all tiles of this group are made so that their edges interlock one with another. Just when the first interlocking tiles were made is not known to the writer, but it was unquestionably much more recently than either of the other two types. It is probable that they were first made in France or Germany, for it is in those countries that we find their greatest development.

The interlocking tile is rectangular in outline, and of various sizes, though at present the manufacturers have settled down very generally to the dimensions of nine inches wide by sixteen inches long. The outer surface of the tile is usually more or less broken by strong vertical lines or corrugations. On the edges are the tongues and grooves which form the locks. The right hand side of the tile is made to form the cover or upper half of the lock, while the left-hand edge carries the under half. The tongues and grooves which form the locks are made single or double or even treble.

The upper and lower ends of the tile are also provided with similar locks, so that all four sides of the tile engage with the edges of four other tiles. In cross section, the interlocking tiles are usually complex—that is, they are neither planes like the shingle tiles, nor simple curves like the old Spanish tiles, nor double or reversed curves like the S tiles. They are usually planes broken at one or more points by a curved roll or rounded elevation, the axis of which is parallel with the longer axis of the tile. Sometimes there are two such rolls, with a plane area between. Sometimes the elevation is not a curve, but is V shaped in cross-section.

The presence of this roll, whatever its form may be, strengthens and stiffens the tile materially in lines at right angles to its axis. In turn, the roll itself requires stiffening with smaller internal ribs or partitions, which hold the tile against warpage on the other axis. Thus supported by the vertical and horizontal cross ribs, this tile is a much stronger, more solid structure than any of the preceding, and consequently it is possible to make interlocking tiles in much larger sizes. Their large size or roof-covering capacity, and their lightness, due to the narrowness of their overlaps, which is about two inches on all sides, makes them much in favor with every one dealing with the subject. The manufacturer likes to make them on account of their rigidity and the consequent small loss in manufacture. Also, on account of their size, few are required for a square—about 135—and as he sells by the square, he can quote a low price. The roofer likes them on account of the rapidity with which he can cover a roof. The architect likes them because of their low weight—about 800 to 850 pounds per square—and because of their mechanical perfection and the permanence of the roof. The consumer likes them both on account of their appearance and their price.

So all in all, from a commercial standpoint, the interlocking tiles are the ones most in favor.

But, considering them from the standpoint of architectural beauty, they are seriously criticised in some quarters, and for this reason their use has largely been restricted to plain structures, like train sheds, power houses, factory buildings and others of like nature—buildings of large roof area, without much pretence to architectural beauty. They are used on buildings of the above classes, largely on considerations of cost, and for this reason the interlocking tiles are destined to be the most important commercial tiles of the world. The other tiles will always have their uses, but the interlocking tiles will surely be the standard commodity.

THE DESIGNING OR PROPORTIONING OF ROOFING TILE.

What has been said thus far has dealt with the design of the tile as a whole, and largely with its acceptability from the standpoint of appearance—the artistic side. We must now take up the more intimate phases of design, viz., the proportioning of the parts of the tile so that it will be able to resist the strains to which it will be subjected. It is one thing to select a superficial form which is artistic and which would produce a beautiful effect on a roof, and quite another to make the tiles economically and with low losses in manufacture and use. The latter problem demands correct settlement of the proportions of the tiles—length, breadth, thickness, overlap, mode of locking, and system of strengthening ribs to guard against warping or breaking. In treating this side of the subject, it will be well to again consider each of the three principal varieties separately.

Shingle Tiles—The ordinary size is six by thirteen by three-eighths inches. The thickness is often allowed to reach one-half inch, chiefly through neglecting to watch the wearing of the die and failing to replace it with a new one or to repair it with new lining. The weight of shingle tiles three-eighths of an inch thick is about 1,100 pounds per square, where one-half inch tiles will run 1,200 pounds or more. Thus the thickness should be very carefully watched.

The edges or sides of the tile are made either square or rounded. The latter form is to be preferred on both practical and artistic grounds. It is extremely difficult to continuously produce square or sharp corners in a column of clay flowing through a die. The corners tend to crack or pull up, or rag or feather-edge, due to the greater friction or resistance of the corners to the passage of the clay. With a rounded edge, the tile-bar will flow much easier through the die, and with far less probability of checking on sides or corners.

When the round-edged tile is placed on the roof, vertical lines are accentuated much more than with square-edged, close-fitting tiles, and this is a great help to an otherwise plain roof.

Again, the rounded corners form air spaces or channels at the under edge of the tile, thus providing open channels for the ventilation of the roof, keeping the sheathing boards dry, and delaying decay.

Interlocking Shingle Tiles.—These tiles are usually made nine inches wide, by thirteen inches long, by one-half inch thick, and require about 190 to the square. Their weight per square runs from eight hundred to nine hundred pounds. At the upper end of the tile on the face or obverse side, two small ribs, about one-quarter of an inch high, are so placed that one is at the extreme edge and the other about one and one-half to two inches lower down on the tile. On the under or reverse side, at the lower end of the tile, are two counterpart ribs, one forming the end of the tile. These ribs act as wind and water-breaks at the ends of the tile.

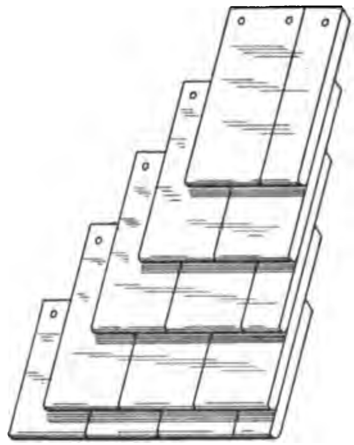

Fig. 9—Round-edged Shingle Tiles.

Along the left-hand side of the tile is a single gutter, into which meshes a corresponding rib projecting downward from the right-hand margin of each tile, thus forming the lateral or side lock.

Fig. 10—Interlocking Shingle Tiles.

The greatest trouble in making this kind of tiles is to get the locks deep enough. If they are made as deep as they should be, then the butt end of the tile is too high, accentuating the horizontal lines on the roof and making them appear out of proportion or harmony.

S Tiles.—The S tile made on an auger machine is usually eleven inches wide by thirteen inches long, with an extreme height of roll of three inches, and average eight hundred to nine hundred pounds per square. The thickest part of the roll is one-half inch and the thin part about five-sixteenths of an inch. These different thicknesses are due to curves of the same radii being used on both sides of the tile in order

that the overlap may fit perfectly. It is usually better to have offsets in the die, which produce parallel grooves through the thick portions of the tile, thus not only making them a little lighter in weight, but assisting in the drying and burning as well. Tiles having these open grooves should not be laid dry; an elastic cement should be used to prevent water and snow from blowing up over the end of the tile, under influence of wind in the proper direction, The side of the tile which is covered by the roll should be made just as high as the roll will allow, thereby forming a good deep gutter.

Fig. 11—"S" or Spanish Tiles, made on an Auger Machine.

Interlocking Spanish Tiles.—In general outline and appearance, these tiles are not very different from the S tiles produced on the auger machine. The real difference is in the side and end locks, but these do not show when the tiles are in position on the roof. In size they usually run about nine by twelve inches, or a little larger, and weigh about eight hundred and fifty pounds per square. In some patterns the lock consists of two raised ribs, running lengthwise, along the side of the gutter, and then crosswise of the upper end of the tile. These ribs are usually three-quarters of an inch high and the same distance apart.

Underneath the roll are two projecting tongues, which interlock with the side ribs on the edge of the gutter. The end of the tile may be made either square or rounded. The latter shape is the more pleasing and lends its form more to the shape of the rest of the tile.

To make this tile perfect, it should have a strong double lock along the side and over the top. The ribs should be fully three-quarters of an inch high, or even more, and the tongue which fits between the ribs should not quite touch the bottom of the groove, allowing room for the water to flow, thus preventing the accumulation of dirt. It is also well

not to have too close a fit, in order to avoid a tendency for this space to fill and remain damp by capillary attraction; also, there should be some play in the locks to allow for slight differences in size of the burned tiles.

Fig. 12
Interlocking Spanish Tile.

Interlocking Tiles.—In this group we find the best representatives of the interlocking principle. A few forms will be shown to illustrate not only good forms of locks for interlocking tiles, but for any other kind of tiles using the interlocking principle.

In the first place, the tile should be so designed that all high parts on the face or obverse side are in the same plane, so that a single flat pallet can be used to place it on when it is taken, soft and easily deformable, from the press. A tile in position on its pallet is shown in Figure 14.

On the back or reverse side of the tile, small cross-ribs should be provided, not only to stiffen it, but to make its nesting or packing more secure and solid.

Fig. 13—Section of a Roof, Showing Interlocking Spanish Tiles.

It will be seen that the French A pattern, Figure 15, has two rather deep valleys or gutters; these carry away the greatest part of the water. Upon long roofs of low pitch, they are often taxed to their utmost capacity. The tiles should also be so designed that they break joints, i. e., the locks in the various courses on the roof should be made to alternate. Thus, the water that gets into the lock of one tile is not transmitted to the lock of the tile next below, but is turned into the broad gutter on its surface.

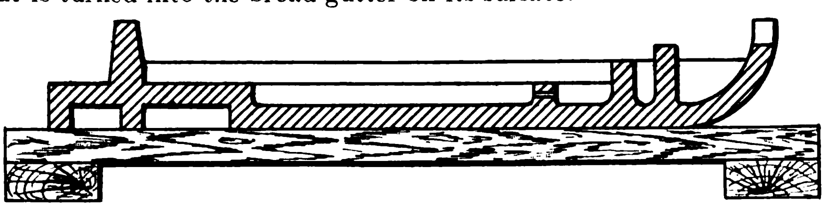

Fig. 14—Showing proper design for an Interlocking Tile to lie Flat on a pallet.

These tiles are usually made nine by sixteen inches, requiring one hundred and thirty-five per square. Each square weighs approximately seven hundred and fifty to eight hundred pounds.

On the general subject of modes of interlocking available for use in tiles, there is considerable of interest. Referring to page 42, a series of sketches show the gradual development of the interlocking idea.

Fig. 15—Interlocking Tiles, French A Pattern.

Side Locks.—*Figure A* shows the simplest form of lock, being merely a single tongue and groove. This lock is not very serviceable. In the first place, it is too shallow, and secondly, the water can enter the open joint at the point marked (a), carrying dust and dirt with it, which soon fills the shallow place under the tongue. The water, being thus blocked, soon fills up the gutter and leaks over onto the roof boards. Tiles provided with this form of a lock should only be used on buildings of little importance, like sheds.

Figure B is a lock of a little better design, inasmuch as the shoulder at the point marked (b) will have a tendency to break up currents of air and prevent them from carrying water into the lock so freely. Also, the dirt will be more likely to lodge on the shoulder (b) and not fill up the gutter.

Figure C. This lock is a very much better one than either A or B, because the open joint is on the side, and covered by the over-lap (c), thus preventing the rain from entering the lock-joint directly. The most serious objection to this lock is the likelihood of its leaking by cross-currents of air blowing into the open joint at the point marked (c) and carrying the water with it on over the entire lock.

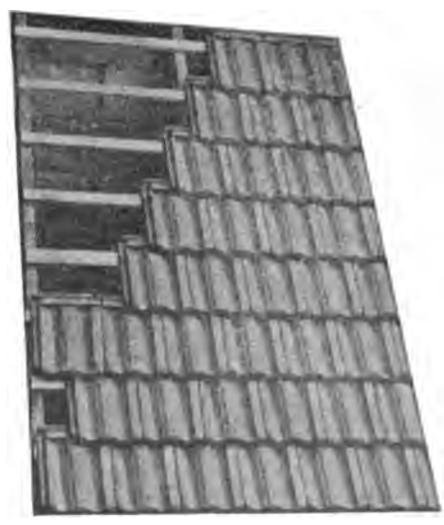

Fig. 16—Showing Section of a Roof Laid with Interlocking Tiles in Which the Locks Break Joints.

Figure D. This lock is again a very decided improvement over any of the preceding; while it resembles B, it is better, because of the protecting lug at the point marked (d) which prevents cross currents of wind and rain from entering the joint from the side, as in Figure C. Also, an improvement over B lies in the fact that an air space is left under the tongue at the point marked (d). This allows the dirt that might enter to be washed away, and also prevents the possibility of capillary attraction, which is apt to cause leaks in Figures A, B or C. The raised portion (d) also makes the depth of the main gutter of the

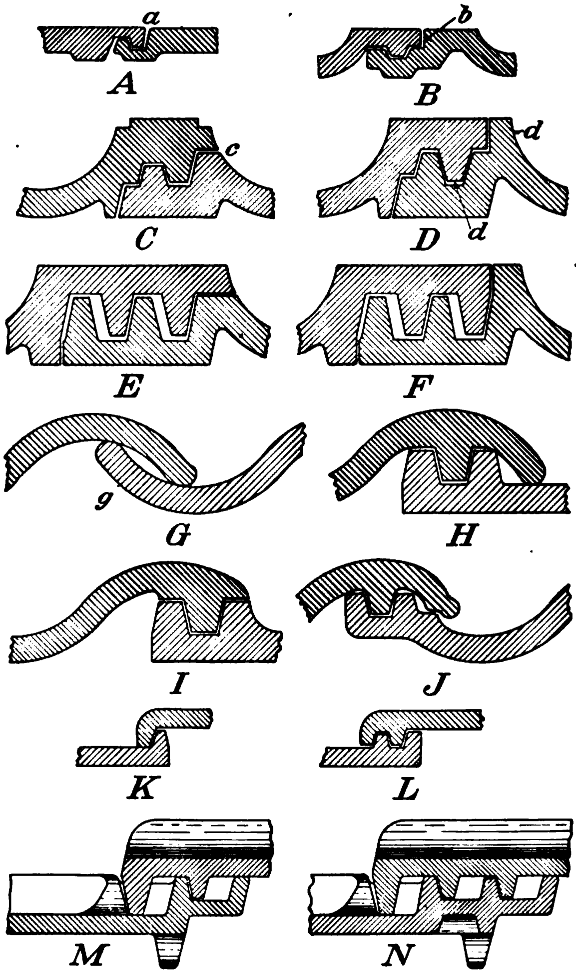

Fig. 17—Showing Various Forms of Side and End Locks.

tile deeper, which is a good feature. This lock is very largely used in this country on the principal brands of interlocking tiles.

Figure E. In E, we have a lock in some respects like C, except that it is double. These double locks make it almost impossible for

wind to blow fine snow or rain through the various turns that would have to be made. This is an exceptionally good lock, there being only one slight drawback, viz., the main gutter of the tile is not quite so deep as in D or F.

Figure F shows a double lock patterned after D, which should prove very effective. The high part at (f) makes the main gutter very deep; with the two lock gutters there should be no trouble from leakage. While locks E and F require the use of more clay than lock D, they should prove very much more satisfactory. Any snow or rain getting beyond the first lock will surely be caught by the second, thus preventing a leaking roof.

There are, of course, still other locks in use, but they are all more or less modifications of the ones shown, and bring in no new principles or added efficiency or economy in manufacture.

Figure G shows the typical lock used on ordinary auger-machine Spanish or S tiles. While this lock is simple, it is very effective. The main gutter is very deep, and the air space (g) tends to break up any capillary flow. However, if the tiles are not straight, and the two contact points are open, fine snow will very frequently blow over the tongue, and, melting afterwards, cause leaks.

Figure H is a fair representative of the lock used most commonly on interlocking Spanish tiles. It will be seen that the lock is a double one, and, as said before, if the ribs are high enough, it will make a very satisfactory lock.

Figures I and J are two other forms of locks used on Spanish tiles, neither of which has any particular advantage over H, and, in fact, are more likely to leak under the influence of winds blowing diagonally across the roof.

Head, or Top and Bottom Locks.—*Figure K* represents the most simple form of a head-lock which can be used, viz., the end of one tile turning up and the next one down. This lock is a very poor and ineffective one. Many tiles have been made with this simple lock, but the day when they can be freely disposed of has passed. The lock does not prevent wind from carrying fine snow and rain over it.

Figure L is a very much better lock and is the type largely used for the head-lock of Spanish tiles. Any snow that may pass the first tongue and groove will be caught by the second one and returned to the outside face of the tile as water.

Figure M represents the typical head-lock for interlocking tiles other than Spanish. It is the one mostly used in the United States, and as a rule proves very effective. It can, however, be improved for open construction work by using the head-lock as shown at N.

Figure N. This is a triple head-lock and should remain dry throughout any storm.

The most vulnerable part of a tile is the joint, both on the side and end. Many of the first tiles used in this country failed to make dry roofs by not having the locks either large and deep enough, or in sufficient number. More attention is being paid by tile manufacturers to the perfection of the locks each year, and such should be the case, for the future of the industry absolutely depends on its being able to furnish strictly water-proof roofs for important structures. It is quite probable that there will always remain a field for the use of tiles of such a grade that they will remain tight under all ordinary storms and might leak *a little* under severe and exceptional stress, for there are many buildings in which a slight and well diffused leakage, separated by wide time periods, would do no real harm. If tiles for such purposes can be made at decidedly lower figures, they will unquestionably find use, but such tiles ought to be sold on this understanding. The trouble in the past has been that the tiles of this grade have been sold under a short-sighted business policy as being fit for a roof of first grade, while, as a fact, they belong to and are fit for only a roof of second grade.

There are also many roofs which may leak more than a little with every windy rain, but which are still good enough for their purpose, and the cheapest grades of tiles without any locks, or only the least efficient, will surely find use for such purposes.

What is needed in the roofing tile business at present is some classification of the product according to its purpose. It is manifestly unfair that the leakage of a cheap tile on a roof of small importance should be considered as an indictment against tile roofs in general. If a tile manufacturer guarantees a roof as water-proof under any or all natural conditions, and it fails, then his blame and responsibility are unquestioned. But if he sells a roof for what it is, then the architect and consumer have no just cause for complaint.

THE RELATION BETWEEN THE DESIGN AND THE PHYSICAL PROPERTIES OF A ROOFING TILE.

It has been shown that the selection of a design for a roofing tile involves a consideration, not only of the artistic results attainable by the use of the tiles in masses, and of the ability of the tiles to collectively make a dry roof, but also of the proportioning of its parts to develop the required physical strength for handling, piling in driers and kilns, storage, and fastening to a roof. The question of color is one that is largely separated from considerations of design, being usually a fixed factor with any single clay, though sometimes regulated by mixture of clays or addition of coloring compounds to them or covering their surface with colored coatings.

The question of the strength of the resultant tile, then, must always be kept before one in designing a tile—any neglect of this point will result

in heavy losses in manufacture and generally by breakage or leakage after application on the roof, owing to inability to stand the shocks and strains incident to ordinary use. This question of the proportions or sizes necessary to give the requisite strength is one which cannot be settled by any arbitrary rules or principles. If clays were a fixed and definite material, or even nearly so, as steel or glass, it would be possible by experiment and calculation to reach a standard ratio of thickness to area, and a minimum of reinforcement or filleting at corners or points of abrupt change in direction of the body of the tile. But since clays in general are anything but fixed or definite, and since even the same clay develops very great variations of strength at different stages in its burning process, and is moreover often subject to fluctuation in quality in the same bed, it is evident that the selection of a design for a tile can only be a tentative matter, and that the tile ultimately developed is very apt to differ more or less widely from the design selected in the beginning. The tile-maker is likely to find that his clay will not flow in a stream of the desired cross section, or that it will not release well from a die of the desired complexity of shape, or that it must be made heavier to endure drying or burning without warping, or that new ribs and reinforcements, not needed or desired, so far as water-proofness is concerned, are required to keep the ware straight and strong. Therefore, a tile design in successful use in a factory almost invariably represents a process of adaption or adjustment between the ideals of design on the one hand and the capacities of the material on the other.

It is not the intention to discuss at this point, the intimate physical properties of the roofing tile bodies as to strength per square inch, etc., but rather to consider broadly the sources of the strength of the product, and the relative desirability of the different internal structures which clay bodies of different sorts are known to develop, especially under the influence of different heat treatments.

The strength of a burnt clay ware is dependent on:

1st. The plasticity or internal cohesion which the mass exhibited in the unburnt condition.

2nd. The assortment of the sizes of the mineral grains composing the mass.

3rd. The extent of the alteration of volume of the mass in drying and vitrification.

4th. The degree of combination, or vitrification of the mineral grains in the burning process.

5th. The cooling of the product from the nearly-fused condition to the atmospheric temperature without inducing cracks or cooling strains.

Taking them up for consideration in order:—

1st. It is a point well known and recognized by clay workers that those clays which show a high degree of internal cohesion or sticking

quality, with which is always associated good or high plasticity, are apt, other things being equal, to make a strong, tough product when burnt. There are doubtless exceptions to this rule, but the use of the adjective "strong" by so many clay workers is a tacit recognition by them of this point. Strong or fat clays, i. e., tough, adhesive, cohesive, plastic clays, make strong products, compared to the products made from "weak" or lean clays, whose properties are the reverse of those above listed.

The bearing of this in roofing tile manufacture is that clays of the lean or weak class are not suited to this purpose, and if used, as they sometimes are, will require extra fitness in other directions, or extra care in firing to make up for this deficiency. In general, roofing tile manufacturers are divided into two hostile camps, producing, respectively, soft, porous tiles and hard, impervious or vitrified tiles. The soft, porous tiles are almost always produced from glacial or alluvial clays which are "strong," and the strength of the tile in its unburnt state is comparatively little increased in the burning process. The hard, vitrified tiles, on the other hand, are frequently, if not usually, made from shales or indurated fossilized clays, which have lost the most of their plastic character during their long existence in rock form, and only developed a partial or feeble cohesion and plasticity in tempering. These clays are "weak" and make a tile which is physically weak and easily broken in handling in the raw condition. But this defect is overcome by their fitness to develop strength in burning. They vitrify well and their product is able to stand alll the physical tests to which it can fairly be put, with credit.

2nd. The assortment of the sizes of the mineral grains of a clay is of importance in two directions—its effect on the strength of the raw clay and its effect on the ease of vitrification in burning. It has been shown that a mixture of coarse and fine particles, in graduated sizes from the finest slimes up to medium sized sands, is productive of tensile strength in an unburnt clay. A clay composed of all fine particles has been found by a number of observers to develop usually only moderate or low strength. The same facts are found to apply to cement concretes where a proper mixture of sizes is a matter of rigid requirement in the sands, gravel and broken stones used in work of importance.

In the glacial and alluvial clays, commonly used in making porous roofing tiles, this variety of sizes of mineral particles is usually found. The fine sizes especially are well represented, insuring the filling of the voids between the coarse particles. In shale and fossil clays, commonly used in making vitrified roofing tile, the ultimate mineral particles are usually very fine indeed, but in grinding and tempering, the paste which is formed is not composed of its ultimate mineral particles. Its grains are usually aggregates or lumps of grains, sticking together and acting

as single large grains, and there is usually a deficiency of fine material. Hence, the product is weak in its unburnt condition.

After burning, however, these relationships are altered. The relatively coarse-grained glacial and alluvial clay, with a large variety of sizes of grains in its component minerals, usually vitrifies slowly and the structure is apt to be porous and less compact when fired at moderate temperatures. But the shale grains, which acted in clots or groups in the plastic state, act more nearly at their true size value in vitrification, and a greater degree of consolidation and body-knitting takes place than in the other case. So that the assorted sizes of grains is found to most generally favor the production of porous tiles, while the use of clays of uniformly fine grain is apt to produce dense, vitrified tiles, all other things being equal.

3rd. The effect of large volume-changes on the strength of the product is a factor of importance. It cannot be considered as operating separate from the considerations Nos. 2 and 4, but its influence can be clearly seen in connection with these factors. In general, excessive volume-changes lead to weak, structurally defective products This is true, whether the change in volume occurs in drying or in firing. This may seem paradoxical, because extensive volume-changes are necessary to develop a highly vitrified structure. But there is a golden mean here as elsewhere, and clays which undergo great shrinkage almost invariably develop at the same time internal flaws, or laminations, or "dry spots," representing the inability of the mass as a whole to contract at the same rate in all directions on account of its shape, or the influence of pressure of other pieces of ware resting on it or similar causes. The result must mean flaws at right angles to the directions in which high tension develops.

Thus, roofing tiles made from glacial and alluvial clays, which shrink at a moderate total rate, usually retain a sound interior structure, and are little weakened by interior flaws, while the tiles made from shales, whose volume-changes are high, in vitrification at least, are often considerably weakened by shrinkage-cracks inside the shell of the ware. Examples can be found in both groups of clay where these properties are reversed, but the above is true in general.

4th. Any clay, on firing, goes through a considerable series of changes or stages from the comparatively weak or unstable raw condition to the comparatively strong and permanent burnt condition. The changes are usually in the direction of increasing density, increasing strength, increasing shrinkage, decreasing porosity and decreasing specific gravity. But in any clay, a point is attained when these changes reach a condition of balance—when the clay is at its best—and further increase of heat leads to a reversal of all these properties. That is, the clay grows less dense, less strong, bloats instead of shrinks, and develops

marked porosity. The strength, therefore, will vary quite widely, according as the burning process is stopped before this culmination, or at it, or subsequent to it.

In the glacial and alluvial clays, the burning is customarily stopped considerably short of the culmination point of the clay's heat treatment, and while its strength is still undeveloped. This is done to retain in the product the quality of porosity, to which a high value is assigned, for reasons discussed later.

In shale clays, the burning is generally carried to fuller maturity and the properties attained represent approximately the greatest strength and minimum porosity which the clay will develop. This is done on the theory that a dense vitrified body is the best for roofing-tile purposes. It will be seen, therefore, that the two hostile camps, advocating respectively porous and vitrified tiles, select their materials, treat them, and fire them, all with a view to developing these two divergent sets of properties.

5th. The cooling of any highly heated clay body is attended with risks—sudden cooling will crack practically any clay product and the thicker and more thoroughly vitrified it is, the more certain it is to undergo cooling strains in excess of its resisting power. Therefore, those who favor the vitrified roofing tiles must take a constantly higher risk of loss in handling their product, than those whose product is porous and which will therefore stand cooling with less likelihood of dunting.

The development of strength has been shown in the preceding discussion to be conditioned on a considerable number of allied and interdependent factors. It has been shown that the pushing of a clay body to that stage of burning which will produce the maximum of strength cannot be done without producing other changes which to some extent are contrary to or harmful to the production of a desirable product. It therefore becomes a matter of judgment, for each manufacturer to decide for himself.

POROUS vs. VITRIFIED ROOFING TILES.

As before stated, this question is an ever present one in the roofing tile industry, and in the nature of the case it is one which never can be settled, for as long as men's minds work independently, so long will the facts be subject to different interpretations.

Numerous examples of ancient roofs covered with both kinds of tile can be pointed out which have by no means gone to pieces, or given any other trouble. Hence, at the outset it must be admitted that each side is partly in the right so far as claiming good qualities for its own product is concerned, and in the wrong in most that they say about the bad properties of the other kinds of tiles. While it is a fact that more roofs built of porous tiles have gone to pieces than in the case of the vitrified

ones, it must not be overlooked that there are hundreds of roofs built of the porous variety to single ones of the vitrified. A comparison, to have value, would have to consider *percentage* of failure in each case. For instance, in France and Germany, the two largest tile centers in the world, the manufacturers are producing hardly anything but the porous tiles. Tiles that have been on roofs in those countries literally for centuries have been found to absorb a high per cent of water. This fact alone should show that a high degree of porosity is not necessarily proof of inability to stand frost and bad weather.

As to the vitrified tiles, no one questions their durability when once in position, but there is an objection to them which is well founded.

It frequently happens that tiles are laid upon a roof of open construction. That is, the roof is not sheathed solidly in the usual manner, but the tile are hung on wooden or iron purlins, spaced apart horizontally on the roof just so as to accommodate the length of the tile. When a roof is so covered, and the roof is examined from beneath, the under side of the tiles are open, or exposed to view.

Fig. 18—Under Side of Open Construction Roof.

For various reasons, among them fire protection, many roofs of the above style are used on boiler rooms, power houses, storage houses, and buildings of like nature. It very frequently happens in cold winter weather that the air in the interior of such a building becomes of high humidity. Such air, upon rising in the building, will come in contact with the under surface of the cold tiles, and will deposit water as dew upon them. Should the roof be very steep, the water thus deposited may, in the case of vitrified tile, course along down from tile to tile, but under ordinary conditions it will form drops or beads of water, which will in time reach a size where they will drop off or drip. A dripping roof often causes much damage and annoyance where expensive machinery or material must be kept dry,

The above tendency of vitrified tiles to form dripping roofs has been the chief argument of the maker of porous tiles against his opponent. He has claimed that porous tiles under the conditions set forth above will never sweat or drip, but instead, on account of their porosity, will absorb the moisture, and gradually evaporate it into the atmosphere on the outside. The fact that it is only in places of the sort described above, and in roofs built as above, that trouble from dripping is observed, is a point in the controversy seldom mentioned by the maker of porous tiles.

The tendency of soft-burned clay products to disintegrate by frost action has been mentioned, and it has undoubtedly caused the failure of an occasional tile and an occasional roof, but it is not a common defect, and it does not occur in many cases when the extreme porosity of the tile seems to invite it. In order to understand this fact it will be necessary to study the clays used, and the method of manufacture pursued.

With very few exceptions, porous tiles are made from the soft or unconsolidated clays, of alluvial or glacial origin, while the vitrified ware comes largely from shale. The fact that few soft clays will stand vitrification in thin wares, like roofing tiles, while shales as a rule will, shows why one kind of clay and one kind of tiles are thus associated. The manufacturer using shale under the ordinary methods of preparation knows that his ware will be too weak and porous, and that it will not stand up under freezing and thawing conditions unless it is well vitrified. Thus each manufacturer is giving the treatment which his material requires, and is doing so under necessity.

The question now arises why, if many roofs of porous ware stood for centuries, is it necessary for the user of shale clays to vitrify his product?

This subject as applied to bricks has received recently very careful treatment at the hands of Mr. J. C. Jones,[1] a digest of whose article follows:

Taking bricks of different degrees of hardness as manufactured from different clays by the soft and stiff mud processes, after determining their absorption and porosity, they were then subjected in a completely saturated state to a severe freezing test, extending through twenty freezings and thawings. The bricks were then crushed, together with unfrozen duplicates, in an Olsen testing machine. The following table shows the results of the freezing test.

[1]Jones, J. C., Transactions Amer. Cer. Soc., Vol. IX, p. 528.

TABLE No. 2.

Result of Jones' Freezing Test.

Kind of Brick.	Grade of Hardness.	Crushing Strength		No. Tested.	Per cent. loss in Strength.	Per cent. Pore Space.	Per cent. Absorption in 15 Minutes.	Remarks.
		Frozen.	Unfrozen.					
Soft-mud Surface Clay	Soft	1194	1374	1	13.1	33.0	83.0	Frozen Brick Scaled on face
	Med. soft	3567	3400	1	4.6	26.9	93.4	
	Med. hard	4289	5315	1	19.9	21.2	92.1	
	Hard	7377	7260	1	1.6	10.2	25.1	
Soft-mud Shale	Soft	2671	2913	3	8.6	26.2	52.9	1 brick Broken in freezing
	Med. soft	4625	5793	3	20.2	17.8	54.2	
	Med. hard	8522	10143	2	16.5	11.6	13.4	
	Hard	7606	11470	4	33.8	5.8	9.6	
Wire-cut Shale	Soft	3729	4637	4	19.6	27.6	40.0	2 bricks broken in freezing 2 cracked in freezing.
	Med. soft	6965	8117	4	14.2	17.1	33.9	
	Med. hard	9165	11315	4	19.4	2.1	34.5	
	Hard	115	11997	4	4.1	0.9	47.3	

Mr. Jones says, "As may be seen, there is little relation between the hardness of the brick and its resistance to frost. The surface clay suffered greatest loss when burned medium hard. The soft-mud shale suffered most when hard burned and the softest brick the least, while with the wire-cut shale brick, the soft and medium hard suffered most and the hard burned much less."

He also points out that there is little if any relation between the amount of pore-space and resistance to frost. This is in accordance with the work of Dr. Buckley[1] on building stones. Jones further says, "The rate of absorption does, however, seem to bear a much closer relation to the resistance to frost than do the other factors. This is true since the rate of absorption is governed by the same factor that controls the rate of flow through the pores, and consequently relief from danger of damage by frost." In conclusion he says, "It is of vital importance to consider the future position and condition in which brick are to be placed, in making tests to determine the ones best adapted. In situations where saturation is the controlling condition, as in foundations, the brick that contains the least pore space is best, but in places where the brick can drain, the one with large pore channels is best."

In further explanation it may be said that the degree of cohesion attainable in bodies made from strong plastic glacial and alluvial clays is very different from that obtained in weak sandy clays, or in shales. The former permit softening under the action of water, and a body of thoroughly mixed and thoroughly adhesive grains ensues. The shale does not soften to the same degree with water, and its comparatively coarse granules do not knit or assume as dense a body structure prior to burning. If burnt to the same degree, represented by an absorption of twelve or thirteen per cent. of water, the body made from the strong clay will probably defy frost, from its highly developed, but not too coarse, intercommunicating pore-system. The body made from a sandy or shale clay will probably be entirely unsafe from frost, on the other hand, because its composite grains, consisting of very fine particles, have perhaps hardened enough and become dense enough, but between the grains themselves, little or no bond has yet been developed, on account of their size and imperfect contact with each other. Their pore-system is coarse, the cavities large, and the elastic strength of the walls of the pore system is yet low. In other words, the structure consists of a mass of grains, themselves sufficiently vitrified to stand frost, but insecurely bound together as yet, and therefore not frost-proof.

The strong plastic clay-body will thus stand while the still granular shale-body will not. But if we now raise the temperature to a point where both clays are reduced to their minimum absorption, there is a very strong presumption that neither will fail from frost. Cer-

[1]Buckley, E. R. Quarrying Industry of Missouri, Mo. Geol. Surv. Vol. 2, Second Series, p. 45

tainly the shale will not, if it be of the type variety. The difference is that when the requisite heat was reached, the shale grains amalgamate and sinter together to a degree that the relatively coarser plastic clay can not equal, and it produces a dense vitrification, in which almost no water is admitted, and in which the factor of strength of the pore walls is very high. The condition of the plastic clay is meanwhile improved also as regards frost strength, though that was not needed, but as a rule it develops warping, sticking or other troubles in burning which make it impractical to use such heat in burning it.

One of the very strongest advocates of porous roofing tiles in America is the veteran tile maker, Mr. Charles Stolp of Chicago Heights, Illinois. He expresses his idea on the importance of adequate preparation of the clay as follows:

"A tile to be durable. though porous, must receive its strength from the preparation of the clay, and not depend on the burning to produce its weather resisting qualities."

One cannot study the methods of roofing tile manufacture in the old world without observing that they fully realize the importance of the above statement. They take superficial clays which have been weathering for centuries, and put them through a most exhaustive treatment of grinding and mixing, after which they still further prepare them by aging the clay in damp cellars for weeks before use. All of this tends to develop the cohesive strength of the clay.

Tiles made from clay thus prepared, though porous, will stand, and have stood, against the severe weather conditions of Sweden, northern Germany and northern Europe, and in this, our own country.

In this connection, the table on page 54 shows the absorption percentage of a number of brands of tiles which have been in use for long periods in this country with excellent results, will be interesting. In all cases, the samples were taken from roofs where they had done service, and the determinations were made by the writer for this purpose.

By reference to the table on page 54 it will be seen that sixteen different tiles were used in this test, representing eight different clays, as follows:

Three shales, three alluvial red-burning soft clays, one shale and alluvial clay mixed, and lastly, one No. 2 plastic fire clay.

It was thought that these samples would fairly well represent the field, not only as to kinds of material used, but in the variations in absolute absorptive capacity and duration of exposure in actual service on roofs.

Tiles A1 and A2 were hand-made, from a soft alluvial clay, and burned to a moderate degree of hardness. Each can be easily scratched with steel. The total absorption for 125 hours was 12.76% and 14.69% respectively. These tiles have seen 35 years service on a roof in north-central Ohio, but they show no signs of weakness or disintegration.

TABLE No. 3.

Showing the Water Absorptive Capacity of Various Roofing Tiles, in Percents.

Designation of Tile.	Duration of Immersion. 15 Min.	1 Hour.	10 Hours.	24 Hours.	48 Hours.	72 Hours.	125 Hours.	Per cent. gain of 1 hour over 15 min.	Per cent. gain of 125 hrs. over 15 min.	Remarks.
A1	9.63	11.82	12.08	12.08	12.13	12.27	12.76	22.74	32.50	Were in use 75 years.
A2	13.41	13.67	13.83	13.89	13.89	14.20	14.69	1.93	9.54	Made from a plastic clay.
B1	5.04	5.56	5.76	5.76	6.22	6.69	7.17	10.31	42.26	
B2	18.30	18.42	18.80	19.08	20.03	20.45	21.02	0.65	14.86	Were in use 92 years.
B3	6.09	7.63	7.75	7.75	8.43	8.80	9.06	25.29	48.76	Made from a plastic clay.
B4	18.46	18.80	18.96	19.63	20.63	21.13	21.46	1.84	16.25	
C1	11.11	11.83	12.86	13.20	13.72	13.89	14.06	0.64	26.55	Were in use 3 years.
C2	11.19	11.55	12.27	12.63	13.35	13.71	14.91	3.21	33.24	Made from a plastic clay.
D1	5.22	5.62	5.82	5.82	5.82	5.82	6.02	7.66	15.30	Were in use 4 years.
D2	1.63	2.61	3.26	3.26	3.26	3.43	3.49	60.10	114.11	Made from shale.
E1	4.24	5.50	5.61	5.78	5.92	6.36	6.86	29.71	61.79	Were in use 15 years. Made from a plastic clay and shale.
F1	0.24	0.24	0.24	0.62	0.80	0.99	1.44	0.00	500.00	Were in use 18 years.
F2	0.61	0.91	1.83	2.04	2.24	2.34	2.65	49.18	318.00	Made from shale.
G1	0.26	0.49	1.31	2.02	2.31	2.51	2.66	88.46	923.00	Were in use 35 years.
G2	0.47	0.70	1.14	1.40	1.73	1.93	2.26	46.80	380.80	Made from a plastic clay.
H1	1.26	3.05	7.31	7.57	7.61	7.61	7.74	134.12	514.20	Were in use 36 years. Made from No. 2 fire clay.

Tiles B1 to B4 inclusive were also made of a soft red-burning clay. It will be observed that there were two soft-burned tiles, and two medium-burned ones in this set. B1, for instance, took up 7.17% of water, while B4 absorbed 21.46%. It goes without saying that this

latter tile is very soft and easily cut by steel, while B1 is scratched with difficulty. Considering the length of time, 92 years, that these tiles were in use, and the high absorption of B2 and B4, it is quite significant that they should have remained in perfect condition.

Tiles C1 and C2 were made by modern machinery and modern methods, from a soft alluvial or semi-glacial clay. While the absorption in these tiles is high, nearly 15%, it should be said that their ability to withstand freezing and thawing is no doubt largely due to the thorough preparation given the clay, thus developing a high internal cohesive strength.

Tiles D1 and D2 were made from shale which had been ground and screened to 18 mesh, pugged in an ordinary pug mill, and then made directly into tiles. It will be noted that the absorption in these tiles is very much lower than in those described previously. While these two tiles have been in use four years in a northern climate, it is the writer's opinion that the one having an absorption of 6.02% is bordering very closely upon the point of failure from disintegration.

Tile E1 has been in use 15 years on a roof in central Ohio. The tile was made from a mixture of clay and shale, prepared by pugging in a pug-mill, and then forming into tile on a hand press. It will be seen that the per cent. of absorption is about midway between the tile made from shale and the average clay tile.

Tiles F1 and F2 were made from a shale. The latter was ground in a dry-pan, and then thoroughly pugged in a wet-pan before being formed into tile by power machinery. These tiles were both harder than steel; although they show an absorption in the one case of over 2½ per cent., they would fall into the class known as vitrified tiles. In fact tiles D1 and D2 are sold as vitrified tiles, but by noting the per cent. absorption it will be seen that they are a long way from being such.

While tiles F1 and F2 were used on a roof in Ohio for 18 years, they have recently been removed from the roof, not from any disintegration or failure of the tile, but on account of the roof leaking. The tiles were very poorly made, and were exceedingly crooked or warped from the extreme degree of vitrification to which they had been burned.

Tiles G1 and G2 were made from plastic clays. G1 was made from a red-burning soft clay, while G2 was made from a plastic buff-burning clay. It will be observed that the total percentage absorption is nearly the same in each tile, but the rate at which the absorption has taken place has been very much faster in the red tile than in the buff. Both tiles were harder than steel, and though in use for 35 years, are as perfect today as when made.

Tile H1 was made from a No. 2 plastic fire-clay, which, after being pugged, was made up by the hand-press method. While the absorption was 7.74 per cent., the tile has withstood the 36 years' use perfectly.

In this connection a paper by Wheeler[1], gives a similar table from his own observations in the field, which is here reproduced:

TABLE No. 4

Absorption of American Roofing Tile (Wheeler).

Designation of Tile.	Per cent. of Water Absorbed in					Remarks.
	½ Hour.	1 Hour.	10 Hours.	24 Hours.	48 Hours.	
A	0.1 to 0.2	0.2 to 0.7	0.4 to 1.4	0.4 to 1.8	0.8 to 2.7	Very dark red, vitrified.
B	....	0.1 to 3.2	0.1 to 3.6	0.3 to 3.7	0.3 to 3.8	Very dark red, vitrified.
B-1	....	0.3 to 1.5	0.6 to 2.4	0.8 to 2.6	1.0 to 2.8	Dark gray, hard burnt.
C	12.0	12.0 to 12.2	12.5 to 12.6	12.7 to 12.8	13.2 to 13.4	Light red, burnt medium hard.
D	0.7	0.9	2.2	2.8	3.1	Dark red, hard burnt and glazed
E	5.4	5.6	5.7	5.9	6.0	Medium red, well burnt.
E-1	....	5.3 to 5.8	5.5 to 6.3	5.5 to 6.3	5.6 to 6.4	Brown, hard burnt.
F	20.0	20.1	20.8	21.5	21.5	Light red, soft burnt.
G	4.0	4.7	5.5	6.0	6.4	Very dark red, hard burnt.
H	0.1	0.3	0.3	0.3	0.3	Very dark red, vitrified.
H-1	1.4 to 2.4	2.1 to 3.8	2.2 to 4.8	2.3 to 4.8	2.4 to 4.9	Dark red, hard burnt.
H-2	....	6.7	6.8	7.1	7.2	Medium red.
H-3	6.5 to 6.8	6.5 to 6.8	6.9 to 7.1	6.9 to 7.1	7.1 to 7.4	Light red, soft burnt.
H-4	11.9 to 14.0	11.9 to 14.0	12.2 to 14.4	12.2 to 14.3	12.5 to 14.4	Very light red, very soft burnt.
H-5	8.4 to 8.7	8.4 to 8.7	8.5 to 8.8	8.5 to 8.8	8.6 to 8.9	Buff, medium burnt.

From the foregoing tables it can very clearly be seen that the percentage absorption of various weather resisting tiles has a very wide

[1]Wheeler, H. A. Trans. Amer. Cer. Soc., Vol. VIII, p. 154.

range, extending in table No. 3 from 1.44 to 21.46, a total difference of 20.04. The highest absorption among the shale tiles is seen to be 6.02 per cent., while the highest from plastic clay tiles was 21.46 per cent. The lowest absorption from shale tiles was 1.44 per cent., while the clay tiles gave 2.26 per cent. as the lowest amount.

From these figures and a study of the durability of the tile in question, it is evident that the percentage of absorption is in no way a measure of the durability of the tile, or its liability to disintegrate. It is quite possible that a microscopic study of the tile bodies would throw considerable light upon this question, and would perhaps give a better way of studying the ability of a tile body to resist freezing, than does the absorption test. The only value that can be attached to the absorption test is its measure of the increased strain or load put upon roof members by rains, or melting snow, which will be discussed a little later.

A second objection to porous tiles is that they become dirty and old-looking very shortly after laying. This is true in many instances especially in districts where much smoke and dust prevails. In cases where the rain water is desired for domestic use, this objection may become one of importance, but in many of our modern buildings it is in many cases desired to have the structure present an old or rustic appearance, in imitation of some ancient building. In such cases, the use of a porous tile has an advantage over the vitrified.

A third accusation against tiles of high porosity is their tendency to absorb large quantities of water during prolonged rains, and thus increase in weight to a degree prejudicial or even dangerous to the roof timbers. Referring to tables Nos. 3 and 4, the maximum absorption recorded in either set of tests is 21.50 per cent. Allowing, for the sake of argument, that every tile in a roof was able to absorb the maximum figure found, and that it was so situated as to have opportunity to become fully saturated, the increase in weight of the roof would not exceed 25 per cent. No roof should be constructed with a factor of safety so small that an overload of several times this amount would in the least endanger it. Similar loading from heavy snow-falls is common in all northern latitudes, and in many cases wind pressures amounting to more than 20 per cent. of the weight are common. Therefore, while an increase of weight from water absorption is an unquestionable fact, still it ought not to be a source of the least danger to a roof otherwise safe.

This argument is rather a "trade talking-point" than a real or serious accusation against soft-burnt tiles. No roofing tiles in use are apt to absorb as high as 20 per cent. Individual tiles may do so, but a whole roof of such tiles would be rare. Further, it is always unlikely that the tiles in a roof will be so situated that total absorption becomes possible. A roof covered with slowly melting snow may easily reach

60 or 80 per cent. of its total absorption, but no higher figures are probable, and while absorbing water on one side, it is usually evaporating it on the other.

The absorption test is more useful in this connection than as to frost resistance, however, and it should be made to note not only the total absorption of the tile, but the *rate* at which absorption takes place.

By reference again to table 3, it will be seen that a number of the tiles absorb from 70 to 90 per cent. of their total amount within the first fifteen minutes. Especially, the soft or very porous tiles, such as A2, B2 and B4, have, at the end of one hour, only increased their water content by less than 2 per cent. over what it was at the end of a fifteen minute immersion. These tiles would throw an increased load of 10 to 15 per cent. upon a roof, during a very short rain storm; while tiles like D2, F1, F2, G1, and G2, would pass through a long continued rain without materially increasing the load. The small increase taken up would be easy and gradual, thus throwing only gentle weight-changes upon the roof.

Manufacturing Conditions.—In the manufacture of the two kinds of tiles, the porous tile manufacturer should *make* his tile before it goes to the kiln, while the vitrified advocate depends on the burning to *make* his tile. In other words, the porous tile should receive much the greatest attention in the preparation of its raw material and in the forming, for if the tile is not strong and solid when dried, it will scarcely harden and strengthen enough in the firing process to make it frost proof. The vitrified tile may be made from granular, poorly-prepared raw material, but if it is of the right vitrifying properties, it may be made durable by hard burning.

Which tile is the more profitable to the manufacturer? The answer should be self-evident. The maker of porous tile, by spending great care in handling the crude, raw material, the working of which can be largely done by machinery, obtains a product which goes into the kiln in sound, straight condition. By stopping the burning at a point where the physical strength, though not at its maximum, is sufficient, he obtains a product which has not undergone severe volume changes, and therefore remains sound and straight and strong, but not brittle. His loss from overfired wares should be nothing, and his loss from warped or cracked or dunted wares should be very low, and his losses from handling, unequal kiln pressures, tilting, etc., should be at a minimum.

With the maker of vitrified tiles it is different. In the burning it becomes necessary to use some system of saggers as supporters for the ware, on account of the great shrinkage and consequent tendency to warpage, cracking, rolling of the ware in the kiln, resulting in wholesale deformation, etc. The handling and breaking of saggers or platform bricks

is an added expense; and in addition a large amount of heat is consumed in heating up this dead material each time. In some few cases, it is feasible to combine two kinds of ware, so that one will serve as the sagger and the other the contained charge, but this condition does not often obtain in roofing tile factories.

As it is desired to have the ware in all parts of the kiln vitrified, it often happens that ware nearest the fire will be overfired and ruined. Then large numbers of the tiles will warp and twist while under a vitrifying heat, no matter how carefully placed in setting, resulting in their loss, or in putting them in the second-class stock or cull. The percentage of good No. 1 wares brought from a kiln of vitrified tiles is very seldom 75 per cent. and the difficulty of disposing of the culls and seconds makes it necessary to assess on the first-class goods a large share of the total manufacturing cost.

Hence, it can easily be seen which manufacturer is spending the greatest amount of money to make his ware durable, when the losses of the two systems are taken into consideration.

If a manufacturer wishes to make use of shale clays, it would be more profitable to him to prepare his clay more thoroughly—that is, grind it extremely fine, temper it and allow it to age in bins until thoroughly. disintegrated—it would then not be necessary for him to burn his product to such a high degree of vitrification in order to make it weather-resisting. The writer firmly believes that with shales properly tempered by grinding and aging, it would not be any more necessary to vitrify the ware than it is with tiles from the soft clays, and it is advantageous not to have the tile too vitreous. If it will absorb water up to about 5 per cent. of its dry weight, it will prevent sweating and dripping when laid on open construction.

PATENTS ON ROOFING TILES.

From the beginning of roofing tile manufacture on a commercial scale in this country, up to within the last decade, it was the general practice for plants to manufacture tiles whose shapes were patented as an invention, either their own, or some one else's operating under royalty.

In fact, from time to time large sums have been paid for patents of roofing tile designs, and in many cases the designs were found to be impractical for manufacture in a commercial way. In one instance known to the writer, $50,000.00 was allowed in stock for a patent on a tile design which was found to be be so expensive to manufacture that no one would use it, if free to do so. It certainly did not need a patent to protect it from infringement. Many of the older companies, that have in the past held patents, have allowed them to run out without effort to obtain modifications which would keep the patent alive.

The time has come, in the manufacture of roofing tiles in this country, that no single design is going to find universal acceptance

or control the market. There are enough unpatented designs of tiles of perfectly commercial grade, in all styles, so that no one should think that a new patent design will protect him from competition. Today, it is a question of producing tiles of the proper quality at the proper price.

As a matter of general interest to roofing tile makers, present and prospective, it has been thought worth while to record in this volume some statistics as to just what has been done in the way of patents on roofing tiles in this country. The data have been compiled from a study of the records of the United States Patent Office. It is needless to say that only a very small per cent. of the patents taken out have ever been followed by actual manufacture of tiles according to the patented design.

Listing these roofing tile patents according to their distribution in the states from which they originated, the order is as follows, including all patents prior to 1909:

TABLE No. 5

Patents Granted for Roofing Tile Designs, Originating in the United States.

State	No.	State	No.
Ohio	30	Kentucky	2
Illinois	19	California	1
Maryland	12	Colorado	1
New Jersey	10	Connecticut	1
New York	10	Kansas	1
Pennsylvania	8	Minnesota	1
Indiana	8	North Carolina	1
Missouri	8	New Hampshire	1
Massachusetts	4	Oregon	1
Iowa	3	Tennessee	1
Michigan	3	Texas	1
Florida	2	Vermont	1
Mississippi	2	West Virginia	1
Georgia	1		
		Total	122

TABLE No. 6
Patents Granted in the United States, for Roofing Tile Designs Originating in Foreign Countries.

Country	No.
Germany	22
England	5
France	3
Denmark	1
Hungary	1
Sumatra	1
Sweden	1
Total	34

Observing the above table it may be plainly seen in what sections of the country the greatest interest and activity has existed in roofing tile manufacture and use. Ohio outranks any other state in the number of patents taken out, as it always has in the number of roofing tile plants. It will also be noted that the southern and western states, which climatically are perhaps best suited to the use of cheap forms of tile, fall far behind. It is only very recently that there have been any roofing tile plants in these states.

Among the foreign countries, Germany leads with over three times as many patents as any other country, while France, one of the greatest tile using centers in the world, has taken out but three patents in this country.

The first patent for a roofing tile design was taken out in this country by J. Parker, August 15, 1835. The tiles were of a form resembling brick, or possibly more like the promenade tile or quarries of today. 'No provision was made for the tiles to overlap or to lock, hence it must have been the intention to bed them in clay or cement, making to all intents a pavement of the roof, very much as the Chinese do at the present time.

The next patent was was taken out in December, 1855, by C. Graessle. This tile was of the interlocking type. One-half of the tile was made in a low half-round; the other half, consisting of the pan of tile, was flat. It was protected on the edge by two parallel ribs, with a gutter between for the tongue of the adjacent tile. That is, the half-round of one tile acted as a cover for the locks on its neighbor. The upper end of the tile carried a lug or projection on the under side, by which the tile could be hung on the roof purlins. On the top side of the upper end of the tile were two cross ribs to form the head-lock, while the lower end of the tile was provided with two counter tongues. Thus it can be seen that a good interlocking tile was devised and the principles of interlocking understood in this country as far back as 1855.

In April, 1858, J. S. Graessle obtained a patent on an interlocking tile of very good design. In fact it is superior to many designs on which patents have been granted since. The tile is constructed with a double locking device on all four sides, and has a broad flat pan for conveying the water.

The first patent on an interlocking shingle tile was taken out in 1867, by Wm. Cranage, of Cleveland, Ohio. The idea in this patent was that of making the tile as though it were composed of two separate parallel plane surfaces of the same size and thickness, of which the upper one had been shifted so that it no longer covered the lower exactly, but left a side and end of the lower plane exposed for a half-inch or so wide, thus making provision for overlapping. This tile would make a very uninteresting roof in any case, for the method of overlapping the edges by extensions of half-tile thickness produced a perfectly plane surface from tile to tile in the same tier, and the only relief was that due to overlap of one tier on another. The vertical lines would thus be lost almost at once, and only the horizontal would be visible, even near by, thus accentuating the characteristic fault of this kind of tile unnecessarily.

The true interlocking shingle tile, having side and end-locks of the regular tongue and groove pattern, did not appear until 1874, when Louis Hamel, of Baltimore, obtained a patent on such a design.

The first patent covering a normal or Spanish tile was obtained in 1873, by Daniel Swain, of Dover, New Hampshire. His plan provided for the use of two patterns, one of which was a broad, concave tile, made flat on the under side, to allow it to sit down flat on the sheathing boards. Rows of these broad tiles were carried up the roof in close parallel lines, allowing each upper tile to overlap the next lower as usual. To cover the joints between the edges of the parallel rows, small half-round tiles were used.

During 1886, three patents were granted for Spanish or roll tiles, with the pan and roll combined in one piece. The first of these was taken out in July, by Albert Aldrich, of New York. His design, however, was impractical to manufacture, on account of the locks requiring undercuts, which cannot be made by ordinary pressing machines. A much better pattern, and entirely practicable to make, was patented by Edwin Bennett, of Baltimore, during the latter part of the same year.

The first patent on a tile design to be run out in bar form on an auger machine and subsequently cut into appropriate lengths was taken out in 1889, by Joseph Repp, of Akron, Ohio. This tile, instead of having a roll or rounded elevation on its face, was made with an angular ridge or inverted letter V, with a pan and a single side-rib. This design was entirely practical commercially, and was manufactured for some

time. This design is of interest chiefly because it was the forerunner of the numerous patterns of auger-machine Spanish or S tiles that have followed.

The first auger-machine interlocking tile to be patented in this country was that of C. Jungst, of Germany, during the year 1887. His tiles are provided with side-locks only, the end-locks being formed by the upper and lower ends of two contiguous tiles overlapping, like ordinary shingle or S tiles.

The largest number of patents on roofing tile designs taken out in any single year was in 1890, when twelve were granted.

The number of patents taken out annually from 1890 dropped off until 1903, when it increased to ten for the single year.

During 1908, there were seven patents taken out, but they were nearly all for cement tiles. For the benefit of those who may be interested in looking up the literature of tile patents more carefully, the following list of patents granted up to February, 1909, has been prepared:

TABLE No. 7.

Consecutive List of American and Foreign Roofing Tile Patents.

Date of Issue.		Name of Grantee.	Number of Patent.	Remarks on Style of Design.
Year.	Month and Day.			
1835	Aug. 15	J. Parker	not giv.	Flat or pavement tile.
1855	Dec. 11	C. Graessle	13,906	Interlocking.
1858	April 27	J. S. Graessle	20,059	Interlocking of fairly good design.
1862	May 6	Samuel M. Logan Philo E. Baker	35,164	Pan tile.
1862	Aug. 19	Isaac Marsh, Jr. Griggs Marsh	36,225	Quarry tile for roofs.
1867	Nov. 12	George Cook	70,805	Improved pan tile.
1867	Dec. 3	William Cranage	71,583	Flat or shingle tile.
1867	Dec. 10	Orville Manly	72,060	Quarry tile to be laid in coal tar and clay.
1870	Oct. 4	William Utley	108,068	Flat or shingle tile, very little change over 71,583
1871	Feb. 21	Charles Howard	111,938	Interlocking tile, poor locks
1871	Dec. 5	John B. Hughes	121,624	Improved pan tile, like 70,805.
1872	July 23	Isaac Hodgson William H. Brown	129,826	Improvement on tile or glass roofs.
1872	Aug. 6	Alexis Roux Pierre Roux	130,156	Interlocking tile with good locks.
1873	Aug. 19	Daniel Swain	142,056	Spanish or normal tile, too heavy.
1874	Feb. 3	Sanford S. Perry	147,018	Improved pan or Roman tile.
1874	Feb. 3	Garry Manvel	147,061	Overlapping or interlocking tile of poor design.
1874	April 7	John F. Graessle	149,469	Diamond tile.
1874	May 5	John T. Weybrecht	150,642	Interlocking tile of French design.
1874	July 14	Louis Hamel	152,991	Interlocking shingle tile, locks good.

TABLE No. 7—Continued.

Consecutive List of American and Foreign Roofing Tile Patents.

Date of Issue. Year.	Month and Day.	Name of Grantee.	Number of Patent.	Remarks on Style of Design
1874	Sept. 8	Edwin Bennett	154,828	Diamond tile.
1874	Dec. 1	Louis Hamel........	157,392	Interlocking quarry tile.
1875	Mar. 2	John M. Lewis	160,445	Interlocking tile of poor design, requires two forms of tile.
1875	Mar. 30	Samuel Mills........	161,538	Diamond tile.
1875	May 4	Garry Manvel.......	162,836	Overlapping or interlocking tile of poor design.
1875	June 8	La Fayette Parker ..	164,203	Diamond tile.
1875	Nov. 30	Calvin T. Merrill	170,582	Diamond tile.
1876	Feb. 22	Jonas Smith	174,021	Diamond tile, two piece.
1876	Mar. 28	Cyrus M. Warren....	175,533	Cement shingle tile.
1876	Aug. 29	Jacob Greenawalt ...	181,670	Diamond tile, slightly modified.
1876	Dec. 26	George Elberg	185,632	Diamond tile modified.
1877	June 26	Philip Pointon	192,451	Diamond tile.
1877	Sept. 25	John W. Hoyt	195,607	Metal tile filled with cement, would be impractical.
1877	Nov. 6	Hiram Stripe	196,773	Improved pan tile, side lock.
1877	Dec. 18	Philip Pointon	198,414	Interlocking tile, poor locks
1878	April 30	Henry E. Merrill	202,953	Diamond tile.
1879	Feb. 4	George A. Taylor....	211,944	Pan tile.
1879	Feb. 4	Edwin Bennett	211,955	Improved diamond tile.
1879	Aug. 26	Frank Waters.......	219,044	Interlocking tile, poor design.
1881	Mar. 15	John J. Williams ...	239,007	Improved quarry tile.
1881	Mar. 22	Lorenzo Lane...... LaurinD. Woodworth	239,104	Diamond tile.
1881	Sept. 27	William Barry	247,596	Flat tile with side lock, poor.
1882	Feb. 7	Thomas B. Atterbury	253,174	Improved shingle tile, not good.
1882	Nov. 21	Lorenzo Lane....... Laurin B. Woodworth	267,904	Diamond tile, improved over 239,104.
1883	Mar. 20	Christopher McCarthy James P. Cumming .	274,354	Interlocking quarry or flat tile, impractical.
1883	Aug. 14	Wilhelm Ludowici...	283,126	Interlocking tile of good design.
1885	May 5	Fawcett Plumb	317,414	Flat shingle tile, method of fastening.
1885	June 23	Paul Simons	320,822	Diamond tile, hollow.
1885	July 28	John E. Donaldson .	322,917	Interlocking flat shingle, would be too expensive to manufacture.
1886	April 27	Frank Hengesbach ..	340,668	Interlocking.
1886	July 13	Carl Weise	345,400	Improved flat or shingle tile.
1886	July 20	Elbert Aldrich	345,942	Spanish tile.
1886	Aug. 17	Henry Hall.........	347,425	Facing or siding tile.
1886	Sept. 7	John C. Litzelle	348,920	Holland pan tile, resembles Spanish tile.
1886	Nov. 2	Edwin Bennett	351,956	Spanish tile.
1887	April 19	E. C. Lindemann....	361,425	Spanish tile composed of two members.

TABLE No. 7—Continued.

Consecutive List of American and Foreign Roofing Tile Patents.

Date of Issue. Year.	Month and Day.	Name of Grantee.	Number of Patent.	Remarks on Style of Design.
1887	Aug. 2	Carl Jungst.........	367,758	Auger made interlocking tile, suitable for cheap structures only.
1887	Aug. 16	John E. Donaldson .	368,386	Interlocking tile, poor locks.
1888	Feb. 7	Edward Walsh, Jr...	377,588	Combined pan and roll tile of glass.
1888	April 10	Arthur W. Cooper ..	380,864	Combination shingle tile and metal roof, not practical.
1888	July 3	Albert Diedrich	385,343	Interlocking flat tile or quarries.
1889	May 21	John Erec Gusten .. / Carl Wm. Braun ...	403,837	Diamond tile.
1889	Sept. 17	Joseph Repp	411,299	Improved auger made tile, the forerunner of the modern Spanish.
1889	Sept. 24	Robert Liddell	411,666	A combination flat and cover or joint tile, not commercial.
1890	Feb. 18	E. C. Lindemann....	421,734	Improved shingle tile.
1890	April 22	E. C. Lindemann....	426,289	Roman or pan tile.
1890	April 29	John E. Donaldson .	426,584	Interlocking tile, very poor locks.
1890	June 17	George H. Babcock..	430,362	Ornamental diamond or scale tile.
1890	June 17	George H. Babcock..	430,363	Improved shingle tile.
1890	June 17	George H. Babcock..	430,364	Scale or modified diamond tile.
1890	June 17	George H. Babcock..	430,365	Eave tile or starters.
1890	June 17	George H. Babcock..	430,366	Interlocking tile known as "Conosera."
1890	June 17	George H. Babcock..	430,367	Hip tile.
1890	June 17	George H. Babcock..	430,369	Gable tile.
1890	June 17	George H. Babcock..	430,371	Corner or mitre tile.
1890	Oct. 14	E. C. Lindemann....	438,321	Interlocking Spanish tile.
1891	Mar. 31	Edwin Bennett	449,397	Pan and cover tile.
1891	Dec. 15	John E. Donaldson / Edward C. Elder ..	465,364	Interlocking tile, locks too shallow.
1892	Jan. 26	Basil Edwards	467,791	Improvement on shingle tile.
1892	June 21	Joseph Martin Wood	477,346	Interlocking tile with method of fastening.
1892	July 5	Joseph Repp	478,171	Improved auger made Spanish tile.
1892	July 26	Frederick N. Marvick / John Walter	479,441	Overlapping flat tile.
1892	July 26	Frederick N. Marvick	479,442	Interlocking tile.
1892	Sept. 27	Henri Sturm........	483,180	Interlocking hollow tile.
1893	Feb. 14	C. W. E. Wutke.....	491,625	Interlocking tile.
1893	May 9	Francis Andrew	497,161	Interlocking tile.
1893	Aug. 8	Max Kaestner	502,725	Diamond tile.
1893	Dec. 26	Andrew M.Cheeseman	511,506	Pan and roll tile combined.
1893	Dec. 26	Andrew M.Cheeseman	511,507	Pan and roll tile combined.
1893	Dec. 26	Andrew M.Cheeseman	511,683	Pan and roll tile, two piece.

TABLE No. 7—Continued.

Consecutive List of American and Foreign Roofing Tile Patents.

Date of Issue. Year.	Month and Day.	Name of Grantee.	Number of Patent.	Remarks on Style of Design.
1894	Jan. 23	Wilhelm Ludowici...	513,430	Interlocking tile.
1894	April 10	George H. Babcock..	517,832	Tower tile.
1894	April 17	John Veen......... F. A. Dornberg	518,294	Interlocking tile.
1894	July 10	John E. Donaldson John Athern.......	522,686	Interlocking tile.
1894	July 10	Samuel K. Cohen....	522,879	Spanish tile.
1894	July 24	Albert Kayser	523,353	Interlocking tile of French pattern.
1894	Oct. 16	Christian Lesmeister	527,431	Interlocking tile.
1894	Dec. 4	H. Niederlaender....	530,119	Interlocking tile.
1895	Mar. 5	Thos. A. Aldridge ...	535,183	Interlocking shingle tile.
1895	April 16	Karl Thomann......	537,732	Interlocking tile.
1895	Aug. 13	Michael Hoffelt .... Matt Hoffelt........	544,303	Interlocking tile, poor locks
1895	Aug. 20	Lucian F. Plympton	544,770	Pan and cover tile, two pieces.
1896	Jan. 21	George A. Taylor....	553,321	Pan tile.
1896	Feb. 11	Clinton Keiser	554,274	Interlocking flat tile.
1896	April 14	Gustav Krebs...... Abraham Weil	558,395	Diamond tile.
1896	June 30	Heinrich Brocker....	562,798	Diamond tile.
1896	Aug. 4	Patrick F. Jones	565,356	Spanish tile.
1896	Dec. 15	Milo Horlocker......	573,328	Interlocking tile.
1896	Dec. 29	Wm. A. C. Waller ..	573,939	Diamond tile.
1897	Mar. 23	Charles T. Harris....	579,481	Shingle tile.
1897	Oct. 26	John J. Merrill	592,474	Interlocking tile.
1898	Feb. 22	Marshall C. Barber ..	599,312	Spanish tile.
1898	April 26	Abraham Weil	602,889	Diamond tile.
1898	May 17	Jacob Freund.......	604,035	Improved auger made Spanish tile.
1898	June 14	Gustav Schulze	605,654	Diamond tile.
1898	June 14	Christian W. Schou..	605,750	Shingle tile with metal locks.
1898	July 19	Henry B. Skeele	607,489	Interlocking Spanish tile.
1899	Jan. 24	Wilhelm Borgolte ...	618,197	Diamond tile.
1899	July 11	Emil Ahrens........	628,737	Diamond tile.
1899	Sept. 12	Hendrick Ludeling ..	633,019	Hollow interlocking tile.
1899	Dec. 12	John E. Donaldson ..	638,802	Small interlocking tile.
1900	Jan. 2	William D. Turnley..	640,338	Glass tile and method of fastening.
1900	May 29	Leopold Gnoth	650,387	Interlocking tile, side locks only.
1900	June 5	Gustav F. Kasch ...	650,939	Auger made pan tile.
1900	June 19	Wilhelm Ludowici...	651,873	Interlocking tile similar to the Spanish.
1900	July 31	Nicholas Daubach ..	654,717	Tile similar to Spanish in connection with a metal-cement joint.
1901	Jan. 14	John W. Carnes	691,239	Interlocking tile, poor design.
1901	Dec. 10	George P. Heinz	688,641	End locks for tile.
1902	June 10	Albert Gustorp......	702,202	Diamond tile.

TABLE No. 7—Continued.

Consecutive List of American and Foreign Roofing Tile Patents.

Date of Issue.		Name of Grantee.	Number of Patent.	Remarks on Style of Design.
Year.	Month and Day.			
1902	Sept. 2	Holden Brock........	708,307	Interlocking tile, no head lock.
1903	Jan. 13	William C. Sharp... John C. Sharp	718,284	Improved shingle tile.
1903	Jan. 27	Frank E. Coombs ...	719,193	Lock for interlocking or Spanish tile.
1903	Feb. 3	Joseph Schall	719,514	Spanish tile, interlocking.
1903	Feb. 17	Jons Nilsson Mauntin	720,831	Corrugated tile made interlocking by means of metal strips.
1903	Mar. 17	Henry B. Skeele	722,918	Spanish tile, interlocking.
1903	June 2	Abraham B. Klay ..	730,131	Interlocking tile.
1903	July 28	Jacob Simmerman...	734,976	Improved shingle tile of glass or clay.
1903	Aug. 18	Johannes Veen......	736,801	Auger made pan tile.
1903	Sept. 15	Henry Ohaus	739,211	Improved shingle tile.
1903	Dec. 15	Carl Schlachter	746,747	Interlocking corrugated or Spanish tile.
1903	Dec. 29	George C. Zwerk	748,141	Shingle tile to be made of cement and metal.
1904	Jan. 12	Walter P. Grath	749,182	Interlocking Spanish tile.
1904	Feb. 23	Henry Baden ..... William Gluss	753,188	Diamond tile.
1904	Oct. 18	Wilhelm Ludowici...	772,363	Interlocking tile, two parts
1904	Oct. 25	Carl Theo Seested ...	773,230	Interlocking tile, with method of fastening, intended to be made of cement, no end locks.
1904	Dec. 6	Walter C. Mitchell...	777,058	Mission tile, two pieces.
1905	April 18	Leslie G. Sharp	787,474	Interlocking Spanish tile.
1905	April 18	Leslie G. Sharp	787,475	Modified shingle tile, to be press made.
1905	May 2	Leslie G. Sharp	788,676	Modified shingle tile, to be press made.
1905	Sept. 12	James H. Perrin	799,259	Diamond tile, two parts.
1905	Oct. 10	Wenzel E. Miksch ..	801,736	Interlocking tile, auger made, no head locks, partly hollow.
1905	Oct. 31	Ludwig J. W. Birn ..	803,524	Interlocking tile, modified "Conosera."
1905	Nov. 14	Henry Meyer	804,754	Diamond tile preferably of cement and metal.
1905	Nov. 28	Lloyd G. Satterlee...	805,884	Modified shingle tile.
1906	Mar. 13	Frederick M. Lensch	814,970	Overlapping corrugated tile, no end lock, preferably made of cement and metal.
1906	Mar. 27	Orvey Price	816,252	Shingle tile, of cement and metal.
1906	April 17	Henry Baden	818,333	Diamond tile.
1907	Feb. 19	Edward E. Johnston.	844,453	Interlocking tile.
1907	Feb. 26	Edward H. Binns ...	845,290	Shingle tile made of strawboard, lime or sand, metal and asphalt.

TABLE No. 7—Concluded.

Consecutive List of American and Foreign Roofing Tile Patents.

Date of Issue. Year.	Month and Day.	Name of Grantee.	Number of Patent.	Remarks on Style of Design.
1907	Mar. 26	Charles C. Davis	848,537	Shingle tile of cement and metal.
1907	April 30	Albert Voigt........	852,402	Diamond tile.
1907	May 7	Edward Coffin	853,063	Diamond tile.
1907	July 23	Ignatz H. Freund ...	860,796	Shingle tile with glass opening preferably of cement, metal and glass.
1908	Feb. 25	Bertel R. Christensen	880,012	Pan and roll, cover tile.
1908	Mar. 10	Edward T. Winslow..	881,522	Corrugated or angle tile in combination with angle covers for the side joints
1908	Mar. 24	Michael Marte	882,765	Shingle tile having an embedded metal hook for hanging the tile. Very impracticable, metal would be destroyed in the burning.
1908	April 21	Carlos N. Bruzand...	885,663	Interlocking tile.
1908	June 2	Joseph Freund	886,595	Interlocking tile, locks imperfect.
1908	July 7	Isham P. Walker....	892,917	Pan tile with separate cover tile.
1908	July 28	Joseph W. Farr	894,489	Cement-metal sheets for roofing, no particular style.
1908	Nov. 10	Samuel A. Jones	903,477	Diamond tile.
1908	Dec. 29	Fred Lotulip........	907,824	Modified shingle tile, impracticable to make on account of under cuts.
1909	Feb. 9	Emery P. Auger	912,057	Cement shingle tile.
1909	Feb. 16	Byron L. Bacot	912,353	Spanish tile, having an impractical lug on the under side.

Other Patents Pertaining to Tiles or Tile Roofs.

1890	July 15	John E. Donaldson ..	432,122	Die for forming roofing tile.
1891	Aug. 25	E. C. Lindemann....	11,186	Reissue of patent 361,425, Spanish tile.
1891	Dec. 8	Mark A. Jackson .. John H. Jackson ...	464,503	Roofing tile fastener, for shingle tile.
1901	Mar. 26	G. A. Nebling.......	670,723	Means for rendering interlocking tile roofs weather proof.
1903	Feb. 24	Henry B. Skeele	721,246	Metal fastener for tile.

As stated before, the day of patented tile designs has nearly passed. The possible variations in the shapes, locks, and mode of attachment of the three fundamental varieties have been pretty thoroughly exploited, and the possibility of a new design being brought out, which could play a new variation of this well worn theme, and still have any real advantage in it over those which have been long since used, is now quite remote. We may fairly say that the roofing tile designs are now pretty well crystallized into a few types. What is needed at present is more tile plants to use these standard patterns in manufacturing tiles of first class color and strength. No one needs a patented design now to compete in the roofing tile business.

CHAPTER III.

THE SELECTION OF CLAYS FOR ROOFING TILE MANUFACTURE.

In the selection of a clay for the manufacture of roofing tile, the qualifications which should be most carefully considered are plasticity, strength, shrinkage, burning behavior and fusibility, color, hardness and porosity.

In a careful search of ceramic literature, no data have been found bearing directly on the testing of clays for roofing tile purposes. In order to give as clearly and as exactly as possible just what the qualifications of a clay should be to make it suitable for roofing tile manufacture, it was thought best in the absence of any previous work, or any kind of recognized standards to go by, to make a thorough study of such clays as are or have been used for successful roofing tile industries, and let the data thus obtained serve as a basis for future judgments as to the fitness of clays for this purpose.

There were in the country in the summer of 1908 fourteen such plants. There were several others which had manufactured roofing tile on a commercial scale at one time, but which had for one reason or another gone out of the business. Samples were obtained from nearly all of the active plants and from some of the defunct ones. Owing to sensitiveness on the part of some of the manufacturers, as to tests of their clay being published, these samples are all listed in the following tables by letters instead of names, so that the source of the samples cannot be established from anything which appears in the report.

For the benefit of interested readers, it may be said that all of the clays of which tests are published herewith were taken either from plants in active operation or recently defunct, and that of the active plants samples were obtained from all but a very few. In one or two instances, the objections of the management to having their clays studied could not be overcome. The list of clays studied, however, is strictly representative of the materials used in roofing tile manufacture in this country. Every type of clay which is used in any past or present plant is represented by one or more samples. In one case, the tile body is made of a mixture of three separate clays and a sample of each clay was taken and tested separately, and another sample of the mixture as a whole.

The samples, with two exceptions, were taken either from the unground clay in the stock shed, or from the ground clay which had

passed the dry-pan, it being desired to obtain the samples unaffected by any tempering operation. In the two exceptional cases, the clays were collected at the end of the pug-mill or tempering machine. As all of these samples were naturally soft plastic clays, it is believed that the tempering has produced but very little difference, and that after drying out and regrinding, they would compare closely with samples taken direct in the pit.

Taking up the various properties of clays, it is deemed best to discuss the bearing that each has on the value of the clay before considering the actual test as carried out.

Plasticity.—Plasticity in clay is the property which it possesses, when mixed with water, of being moulded into desired shapes and of retaining its shape after moulding. It is not necessary to here go into the cause of plasticity, for which a number of theories have been advanced, none of which have been fully accepted, nor have any practical methods been devised for the measurement of this valuable property of clays.

Among practical clay workers, such terms as plastic, very plastic, poorly plastic, or medium plastic are used. Fine grained plastic clays are known as "fat," while sandy or coarse grained ones are termed "lean."

The amount of water required to develop the plasticity of a clay is to a certain degree a measure of its plasticity. The finer the grain of the clay, the more water is required to develop its plasticity. In ball clays, for instance, as high as 30 or 40 per cent. of water may be required to get the best plasticity, while some shales will only need from 15 to 25 per cent.

The samples of roofing tile clays as described above were tested as to the amount of water required by each for plasticity. It was not possible to tell when the different samples reached the same degree of plasticity by any other test than the ordinary sense of feel. When tempered to a point where they felt right for manufacture, the amount of water was determined accurately, with the following results:

TABLE No. 8.

Showing Per Cents. of Water Added to Develop Working Plasticity in the Standard Roofing Tile Clays.

Designation of clay.	Percentage of free water contained	Designation of clay.	Percentage of free water contained.	Designation of clay.	Percentage of free water contained.
A	18.31	F	20.65	K	18.97
B	15.22	G	13.82	L	17.21
C	22.22	H	21.22	M	15.86
D	20.35	I	15.99	N	16.13
E	19.16	J	20.83	O	18.74

From table No. 8 it will be seen that Sample G is the only one that requires less than 15 per cent., while none of them reach very high figures. Sample C, with 22.22 per cent., is the highest. The average of all the samples is 18.31 per cent., which is about the same as shown by clays used in stiff-mud brick industry and similar processes.

By reference to table 8 it will be seen that in a general way the clays requiring the larger amounts of water to develop plasticity are also the ones that develop the highest drying shrinkage which would indicate a connection between the degree of plasticity, the water used in tempering, and the shrinkage in drying. Clays for roofing tile manufacture should have a moderate degree of plasticity—sufficient to permit of their being easily worked, or moulded into the desired shapes, but excessive plasticity is dangerous, in that it indicates a similar excess in air shrinkage and the other drying qualities of clays and excessive lamination of the clay in manufacture. Clays with the highest degree of plasticity are the ones most likely to crack in drying. Then, too, the excess water that must be used in tempering extremely plastic clays causes increased expense in drying, as well as being more apt to dissolve soluble salts and bring them to the surface of the ware as a scum or whitewash. The tempering water is frequently highly impregnated with soluble salts, hence the use of less water in tempering the less plastic clays is an advantage.

Strength.—The strength which a clay develops on drying is very important to the roofing tile manufacturer. His ware, for the greater part, is of thin cross section, and unless the clay has a fairly good strength, large losses will result in handling the ware during the setting, and still greater losses will occur if the ware is set without saggers, or some form of kiln supports, as roofing tiles are being set at the present time in several of the plants. In other words, the clay should possess strength enough to resist the crushing strain of the superimposed tile, in such modes of setting as are otherwise most economical. It is not known that all the factors influencing the strength of a raw dry clay are definitely determined, but some at least of these factors may be recognized.

Upon evaporating from a clay, the water previously added to produce plasticity, the clay particles are drawn closely together, and the grains develop a cohesion between each other. By some, this strength is thought to be due to an interlocking of the clay grains, while others contend that it is due to the cementing power of colloidal matter developed by the action of water on clay particles.

The strength is usually measured by the so-called tensile test using a small brickette, having a central cross section of one inch square, and widened ends which are caught in the jaws of clamps. An increasing load is very carefully applied, breaking the brickette at the narrower part by a steady pull. For some purposes, this test will

probably answer, but in testing a clay for roofing tile purposes it was thought that the cross breaking strength would give data nearer to the actual conditions to which such clays are exposed in practice. The following test was devised for this purpose:

The trial pieces were made from the standard roofing tile clays, all of which had previously been carefully ground and screened to pass a 20-mesh screen, this size being commonly used commercially. The clays were then mixed with water by hand upon a clean table, until each clay had been made a little softer than was considered its proper working condition. Each clay was then made into a large ball-shaped lump, containing from 30 to 50 pounds. These balls of clay were wrapped in wet burlap and packed in damp boxes, made of plaster of Paris. The clay was allowed to remain in the damp boxes for at least 48 hours, when each in turn was removed, placed on a wedging block and thoroughly reworked. It was found that in nearly every instance the clay had assumed a nice condition; that is, the water added for plasticity had become evenly distributed, and the clays had mellowed or toughened to a very marked degree.

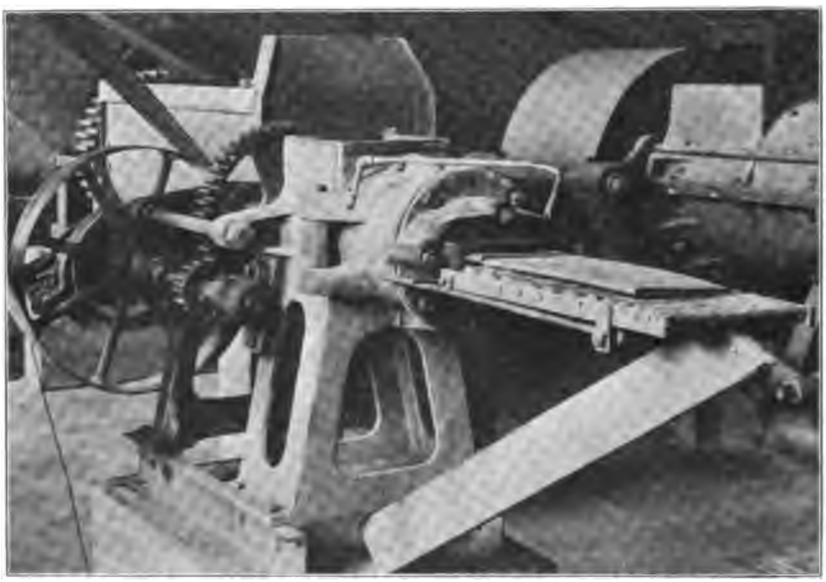

Fig. 19—Mueller Auger Machine.

The trial pieces for the cross breaking tests were made by running the different clays through a small auger-machine made by Mueller Bros., St. Louis, Missouri, shown in the above illustration.

The bar was approximately one-half inch thick by six inches wide, and this was cut into fourteen-inch lengths. Each tile was then carefully cut lengthwise in the center, producing two strips three inches

by fourteen inches by one-half inch. These were placed on boards to dry in an open room at ordinary room temperature, up until the time of testing, when they were placed in a drying oven, and heated to 212° Fahrenheit for 24 hours, being removed from the dryer a few at a time as needed for testing. They were first allowed to cool to about atmospheric temperature. In most of the clays, eight trial pieces were used to make this test, while ten were used in a few.

The object in using the auger-machine to make the trial pieces was to eliminate the personal factor in moulding as much as possible. In addition, the bar of clay was thus made under actual working conditions and in the full size, though subsequently cut up. The trial pieces were carefully measured by calipers having a Vernier scale, correct to the second decimal place. The thickness and width of each bar was thus taken.

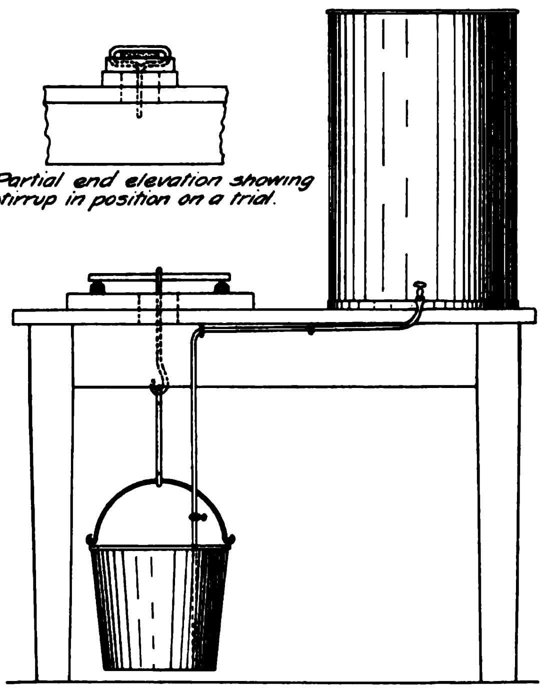

Fig. 20—Cross-Breaking Machine.

The actual test of breaking the trials was accomplished by the use of the apparatus shown in Figure 20. It will be observed from the cut that the test piece to be broken was supported upon knife edges, made of hard oak, and placed ten inches apart from center to center. A stirrup having a knife edge resting on the bar of clay, and a hook at its lower end, was placed midway between the end supports. A pail or bucket was then attached to the hook as shown. The actual breaking

load or weight was supplied by water from the tank on the table. A small rubber tube was used to convey the water from the tank to within an inch or so of the pail bottom as shown. Attached to the rubber hose was a pinch-cock, which was closed the instant sufficient water had been run into the pail to break the piece. By keeping the hand upon the pinch-cock constantly, it was possible to shut off the supply almost instantly, or at least with only a small factor of error.

After each breaking test, the pail and its contents was carefully weighed, the water returned to the supply tank, and the operation repeated.

Each breaking weight has been calculated into load per square inch in the following table:

TABLE No. 9.

Results of the Cross-breaking Test as Applied to the Standard Roofing Tile Clays. Bars One-half Inch by Three Inches in Cross Section.

Designation of clay sample.	Load in pounds per square inch.	Designation of clay sample.	Load in pounds per square inch.
A	6.33	H	11.50
B	6.41	I	6.98
C	5.95	J	8.78
D	4.17	K	7.04
E	7.53	L	not determ'ed
F	5.04	M	4.79
G	2.76	N	9.05
		O	not determ'ed

From the table it will be noted that clay H stood the greatest load, 11.50 pounds, while clay G was the lowest, only requiring 2.76 pounds to break it. Clay G was extremely brittle or short, and was very hard to handle without breaking. Clay D, while much better, was still too weak. Care would have to be exercised in working with it. Those clays having a cross-breaking strength of 5 pounds or more per square inch were all safe to work with. Clay H would stand very rough handling in setting, but this advantage is offset by having a higher shrinkage than the other clays.

Clays of the type of A, B, C and F are good commercial clays, in so far as strength of the unburned, dried ware is concerned.

Figure 21 is a graphic representation of the necessary loads to break the various trials.

Air Shrinkage.—The volume changes of clays are preferably studied in two stages, proceeding from dissimilar causes; viz., the drying or air shrinkage and the burning shrinkage, Only the former will be considered here.

The water which is added to a clay to make it plastic is lost by evaporation, causing a loss of volume. The loss of volume or shrinkage

varies greatly with different clays, and with the same clay under different modes of treatment. The amount that a clay will shrink in drying is best expressed in per cents. of the initial length as linear shrinkage, or of the initial volume as cubic or volume shrinkage.

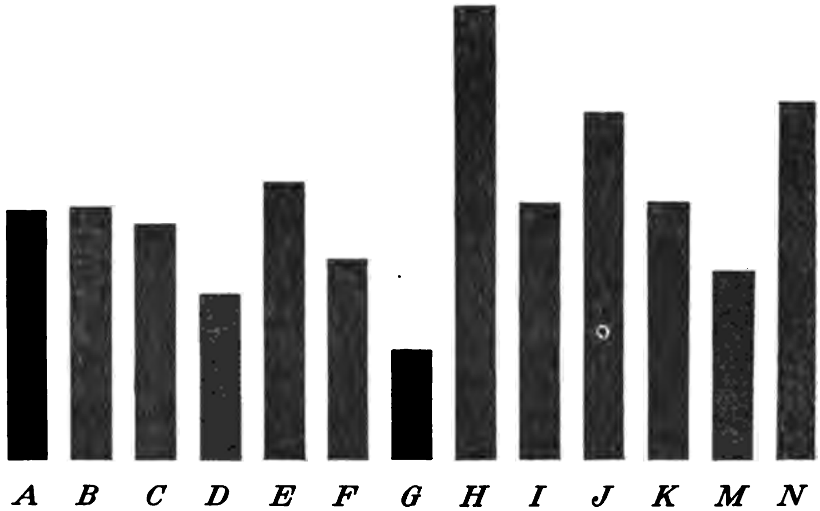

Fig. 21—Graphic Representation of Relative Cross-Breaking Strength of the Standard Roofing Tile Clays.

Purdy[1], in a very careful and extensive test on the measurement of linear air shrinkage of clays, says that this factor varied as much as 133 per cent. from the average, and that such data must be wholly unreliable. Although extreme care was exercised in preparing and handling the test, he says that the large variations in the results were a surprise to the operator.

The volume air shrinkage was found to vary within much more reasonable limits, although such variations as 33.8 per cent. were found. The reasons given for such errors are charged to the smallness of trial-pieces and the personal factor. In view of Purdy's results, both linear and cubic shrinkage were carefully measured on the standard roofing-tile clays as a possible check, one to the other.

Linear Air Shrinkage.—Taking up first the linear air shrinkage: The trial-pieces were made by taking the previously prepared and aged clay, and passing the same through a one-inch by one-inch die attached to a small plunger or piston machine. The clay was fed into the barrel of the machine in lumps or balls, packing the chamber as full as possible. The plunger was then moved forward by a screw movement, and as the clay issued from the die it was cut off into four and one-half inch lengths. Ten trial pieces of each clay were thus made. These bars were placed on metal pallets, lettered, numbered, and stamped

[1]Purdy, R. C. Illinois State Geol. Sur., Bull. IX, p. 133.

with a 100 mm. distance marker. To determine the water added for plasticity, the trials were weighed upon leaving the die. Then, at intervals, they were weighed and measured, giving the results in Table 10.

TABLE No. 10.

Table showing loss of Water, and Corresponding Air Shrinkage of the Standard Roofing Tile Clays, from Time of Making to Complete Dryness.

Designation of clay.	Per cent loss of water.	Per cent of drying shrinkage.
A	4.19	1.75
	7.69	4.50
	16.78	5.00
	19.23	5.50
	20.75	5.50
	20.62	5.50
B	3.18	1.50
	9.26	2.75
	15.01	3.00
	15.97	3.00
	16.22	3.00
C	5.71	2.00
	13.21	4.50
	21.42	4.50
	23.21	4.50
	24.28	4.50
D	13.88	3.50
	20.48	3.50
	21.52	3.50
	21.87	3.50
E	6.25	4.00
	15.97	6.00
	20.83	6.00
	21.52	6.00
F	6.94	4.00
	17.01	5.00
	21.52	5.25
	22.22	5.25
G	1.80	.50
	7.34	2.00
	13.85	2.00
	15.66	2.00
H	3.54	2.00
	5.67	3.50
	12.05	6.50
	19.85	7.00
	22.62	7.25
I	2.00	1.00
	6.66	3.25
	10.00	4.00
	13.66	4.00
	15.33	4.25
	16.33	4.25
	17.33	4.25
J	6.33	2.50
	8.80	3.50
	13.73	5 50
	20.07	6.00
	21.47	6.50
	23.94	6.50
K	6.25	3.00
	9 02	4.00
	12.50	5.00
	17.35	5.50
	19.79	6.00
	20.48	6.00
L	1.80	1.00
	3.31	2.00
	5.92	3.50
	6.18	4.00
	9.98	5.50
	11.43	6.00
	13.38	6.00
	19.12	6.00
	20.56	6.00
M	1.54	.50
	3.08	1.50
	5.27	3.00
	9.40	3.50
	11.53	3.50
	13.58	3.50
	17.14	3.50
N	1.95	1.00
	4.02	2.50
	5.21	4.00
	6.84	4.00
	10.28	4.50
	12.33	5.00
	13.90	5.00
	16.90	5.00
O	2.09	1.00
	3.82	2.00
	6.42	5.00
	7.30	4.50
	11.95	5.50
	12.48	5.50
	13.32	5.50
	17.52	5.50
	21.90	5.50

In order to make this mass of data easier to interpret, it has been plotted to scale on co-ordinate paper, and the points connected, making the curves shown in Figure 22. The irregularity of the periods for taking readings and the few readings obtained in the early part of the drying tests leave much to be desired, but, after all, the curves are of assistance in visualizing the data. From these tables and curves, it is possible to divide these fifteen clays into two tolerably distinct groups.

First. Those clays which continue to show a steady shrinkage as long as the expulsion of water continues. Samples J, H, K, I and E belong here. J is the type, continuing to shrink up to 21.5 water loss out of a total water expulsion of 24.

Second. Those clays which cease or nearly cease shrinking when 50 per cent. of the water has been expelled. Samples O, A, F, L, N, M, G, B, D and C belong here. O is the type, being almost through shrinking at 6 per cent. water loss, but continuing to lose water up to 22 per cent.

The second group may for convenience be divided again into subgroup A, those which show a high shrinkage—5 per cent. or above—as O, A, F, N and L, and subgroup B, those which show a low shrinkage—4 per cent. or below—as G, B, D, C and M.

The theory has been long held that the water required to make a clay plastic must be in excess of the interstitial or pore space of the clay, and that after this open space is filled then further addition of water widens the distance between grains of clay, causes them to float and move on each other more easily, and by its subsequent removal causes the shrinkage of the clay in drying. This theory is borne out by the curves shown in Group 2, both in the high and the low sub-groups. But in Group 1 we have clays whose behavior does not at all agree with this familiar conception of the mechanics of a plastic clay mass. These clays become less in volume almost up to the very last of their water supply, and if these data can be reproduced and extended in other clays, they would call for a remodeling of this old conception.

It is believed that this method of examining the drying properties of clays by plotting the shrinkage vs. loss of water in curve form promises to be of practical value.

For example, take clays of the type of G or D. It can be seen at a glance that these clays could be dried easily and safely up to the point of their maximum shrinkage. Their loss of water has a relation to the shrinkage of four to one or above, while clays like H and K, having a relation of the loss of water to shrinkage of about three to one would be more difficult to dry. In other words, their rate of drying would have to be decreased to about one-half of that required for G and D.

Again, clays H and K would have to be dried very carefully right up to complete dryness, while clays like G and D could have their rate of drying forced, from the time at which their shrinkage ceases, up till all water is expelled.

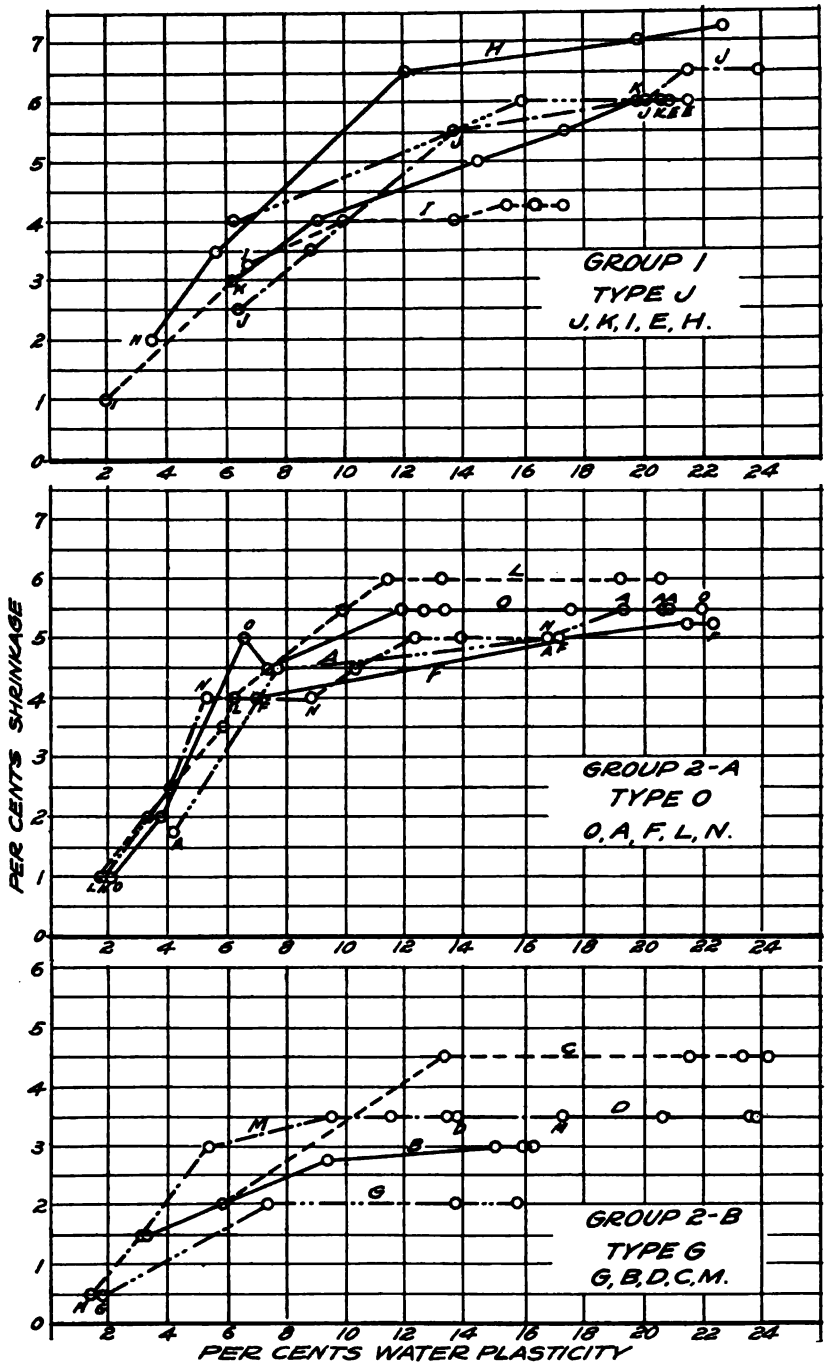

Fig. 22—Curves Showing Rate of Shrinkage in Drying.

Trial Pieces for Volume Shrinkage.—Owing to the die used for the linear shrinkage trials being improperly constructed, and requiring too much time to produce a perfect bar, it was discarded and a new outfit used for the volume trials. This consisted of a cast iron die box having a two-inch by two-inch opening extending through it. Closely fitting the opening was a piston which was used to compress the clay in the mold and then to expel the same. The clay was carefully made into a roll that would just enter the opening. The die standing vertically on a table, the roll of clay was dropped in, the piston was inserted and then pressed down until the clay completely filled the die. Turning the die box on its side, the rectangular mass of clay was forced out. This piece, approximately two inches by two inches by four inches, was now cut into cakes three-fourths inch by two inches by two inches by means of a wire cutter. Ten trials were thus made. Finally, each in turn was returned to the same die box and firmly repressed, to destroy the rough edges and surfaces from the wire cuts. Each trial was at once weighed, lettered and marked with a 50 mm. marker. Then all were placed in pans of water-free kerosene, where they were allowed to remain twenty-four hours. Each trial in turn was then measured for its volume in a Seger volumeter.

The volumeter consists of a glass jar with a capacity of about four litres, having a broad mouth and closed with a ground glass stopper. Through the center of this stopper is a circular opening, into which fits a glass tube, which has an expanded bulb at its upper end. Through this bulb and tube the interior of the jar is open to the air.

At the base of the jar in one side is a glass stop cock, which is connected to the burette shown to the right of the jar in the cut. The burette holds 125 cubic centimeters, and is graduated to tenths of a cubic centimeter. The upper end of the burette is expanded into a bulb, which acts as a reservoir for the liquid drawn up from the jar by means of suction applied to the top of the burette. The glass tube inserted in the stopper of the jar has a zero mark placed upon it, just below the bulb. At the same level on the burette is a second zero mark. Thus the apparatus is standardized by filling the jar until the liquid exactly reaches the zero marks.

To use the volumeter, oil must be used for the unburned trials, while water could be used for any substance that will not disintegrate when immersed in it. After the jar has been filled to the zero marks, the oil is sucked or drawn out of the jar up into the burette and its bulb. When a sufficient quantity has thus been removed from the jar, the stop cock in the burette is closed. The glass stopper is then removed from the jar, and the trial piece which has been previously saturated with oil is lowered into the jar, the stopper replaced, the burette stop cock opened, and the oil allowed to run back into the jar, care being taken to stop it exactly at the zero mark in the glass

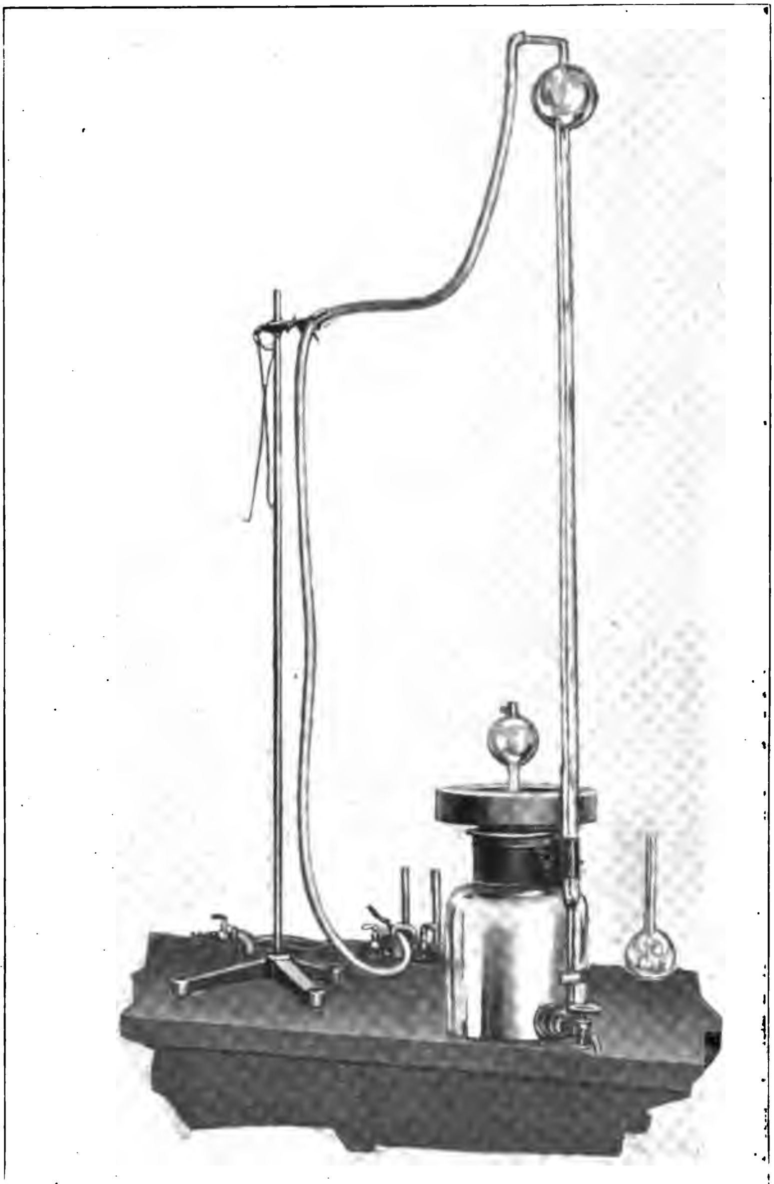

Fig. 23—Seger Volumeter.

stopper. There will remain in the burette, and measured by it, a volume of oil in cubic centimeters equal to the volume of the trial piece placed in the jar. After the volume has been read off, a portion of the oil is again drawn up the burette, the trial piece removed, and a second stan-

dardization of the liquid made. Thus the work is carried on. Much care must be given to the operating of a volumeter in order to get consistent data; many small factors creep in to vary results. For instance, after the oil has been drawn up into the bulb of the burette, a trial placed in the jar, and the oil allowed to flow back, it will be found that unless a considerable time is allowed for the oil to drain down the sides of the burette, that an error of considerable importance will be made—that is, the volume will be underread. Again, much care should be used in having the trial pieces free from excess oil upon entering the jar and in seeing that the oil is not spattered out or lost upon removing the lid.

For lowering the trials into the jar a little device was used consisting of a piece of flat sheet iron, so bent that the step formed had its center of gravity directly under its vertical part. In the top of the piece was a hole, through which the lifter and its charge could be raised or lowered into and out of the jar by means of a small hook. The lifter must of course be left in the jar while standardizing.

All of the trial pieces used in this test were prepared as before noted, and their volume carefully measured in the volumeter. After being removed from the volumeter, they were allowed to air-dry for several hours, and then placed in a drying oven and brought to dryness, after which they were carefully weighed, measured and allowed to soak in oil a second time, this time for a period of 48 hours. The volume of each trial piece was again taken, giving the following results based upon the average:

TABLE No. 11.

Comparing the Volume Shrinkage of the Standard Roofing Tile Clays with Their Measured and Calculated Linear Shrinkage and Water Content.

Sample	Average Initial Water Content in Per Cents.	Average Volume Shrinkage in Per Cents.	Average Measured Linear Shrinkage in Per Cents.	Calculated Linear Shrinkage in Per Cents.
A	16.01	13.47	3.94	4.71
B	14.23	7.34	3.32	2.51
C	20.16	12.63	4.90	4.40
D	18.80	8.60	3.90	2.95
E	16.80	12.43	3.94	4.33
F	19.08	12.96	4.03	4.52
G	11.37	3.09	1.66	1.04
H	19.83	19.36	6.00	6.92
I	14.69	8.49	3.96	2.92
J	17.72	17.02	5.98	6.03
K	17.47	13.93	4.88	4.88
L	16.67	16.96	4.88	6.01
M	15.58	8.25	3.92	2.83
N	16.13	9.38	3.46	3.23
O	18.74	12.08	3.82	4.20

The above figures of volume and linear shrinkage, with the per cent. of initial water, are taken from the average of ten samples in each case. The linear shrinkages given in column 5 were calculated from the observed volume shrinkage by the Purdy formula.[1]

While the measured and calculated shrinkage do not check each other closely, there is a very general similarity in them.

Much care was taken in obtaining the two kinds of measurements. The linear shrinkage marks were cut into the trial pieces by sharp-pointed dividers, set to read 50 mm. When the trial pieces were dry, they were measured by a Vernier shrinkage scale, which read to the second decimal place. The differences in the measured and calculated shrinkages no doubt come from the inability of clay bodies to shrink perfectly. Structural flaws form inside clay wares, owing to the inability of the highly viscous mass to completely obey the laws of a fluid. No piece of plastic clay ware can be broken open and found free from structural defects. Hence, no formula based on a perfect volume change can be expected to agree other than superficially, where it is known that the volume change is highly imperfect.

It will be noted that clays H and J have the highest volume and linear shrinkages of the entire list, while clay G has the lowest. These same clays have the highest and lowest per cents. of initial water. By referring to Table No. 8, it will also be seen that clay H has the greatest cross-breaking strength, and clay G the lowest. Thus we can see that in this case there is a close relation between the percentage of water required for plasticity and the shrinkage and strength of the clay.

BEHAVIOR IN BURNING.

The properties which weigh in making one clay more desirable to work than another in the burning process are:

1st. Freedom from a tendency to snap or pop in heating up.
2nd. Ease of oxidation.
3rd. Wide vitrification range.

Nearly any clay can be burnt successfully if sufficient time and skill and expense can be brought to bear on it, but the ease with which some clays can be burnt and the difficulties which arise with others make these properties of very real importance in estimating the value of any given sample.

The properties which are developed in the clay by the burning process—the color, strength, hardness, frost resistance, volume change etc.—are really separate from the actual behavior in burning and will be considered under a later heading.

[1] "If a unit cube shrinks so that each edge is decreased by linear length 'a,' then the new length of the edges becomes $(1-a)$. If the decrease in volume of this same cube be represented by 'x,' then the new volume will be $(1-x)$. Since the edges of the cube are now $(1-a)$, its volume can also be represented by $(1-a)^3$ hence $(1-a)^3$ is equal to $(1-x)$, or $a = \sqrt[3]{1-x}$." (Bull. IX, Illinois Geological Survey p. 133.)

Snapping.—This peculiarity is not a very common defect of clay wares, but is a serious drawback to a clay when it does occur. The clay on heating shatters or flies to pieces explosively, in whole or in part, and not only ruins the piece affected, but often does much harm to the surrounding pieces—especially if they be glazed and subject to easy disfigurement.

The idea is common that snapping or popping is due wholly to the too rapid expulsion of moisture, so that steam is generated faster than can escape from the pores of the clay, and, as a consequence, flakes or chips of the ware are blown off to vent the interior pressure. Beyond doubt such steam explosions do occur, and commonly too. Especially in piston-made wares, like sewer-pipe, in which longitudinal laminations are extensively produced in the die, the steam seems to collect in these cavities and blows off large flakes, and the resultant product is usually worthless or nearly so. Any clay will fail from this cause, if its treatment is conspicuously over-hastened, and time is not afforded for the water to peacefully vaporize, but in general those clays which give the most trouble are the fat, rich, plastic clays of tight body. Such clays manifest a stronger tendency to laminate, or to form layers separated by cracks or unbonded zones, and thus help to produce this defect, both by hindering the easy escape of steam and affording accumulation zones for it to gather in until the danger point is reached. Weak, porous, sandy clays are not given either to holding back the steam or forming laminations, and hence in such clays steam-popping is at a minimum.

But this form of popping is the easiest to regulate, because its causes are understood. Real snapping is not due to this cause. It develops in thoroughly dried clay wares and hence cannot be a water or steam trouble. Clays affected by it fly to pieces or chip off from the surface and give great trouble. In general it is close-bodied, dense clays which snap. The cause has never been adequately studied, but is probably due to unequal expansion or too rapid heating. In the fifteen samples tested for this report, no snapping occurred in any of the trial pieces produced, showing that these clays are not affected. In another clay, subsequently tested in the same manner, snapping did develop. The likelihood of developing trouble from snapping is greater, of course, in laboratory experiments in small kilns than in large kilns in commercial work, on account of the tendency to quick heating in small kilns.

Oxidation Behavior.—Clays contain a number of mineral and organic constituents, besides the silicate of alumina which constitutes the plastic cementing material which gives character to the mass, and in burning a large number of different chemical reactions may be occurring. In general, these reactions are of two sorts—destructive and con-

structive. The former tend to break down the original constituents, drive out all of the volatile elements, and bring what is left into a condition of quiet equilibrium—i. e., a state where further chemical changes are not taking place. Only the less volatile substances usually remain when the clay has reached this stage, such as silica, alumina, iron, lime, magnesia, and the alkalies, and these substances are present partly as free oxides, and more largely as silicate compounds, more or less broken down from the mineral forms in which they originally existed.

The second or constructive changes are those occurring in vitrification and fusion, by which the oxides and minerals left in the clay mass are brought into new union by additional heat, and with this new partial combination comes a new set of physical properties, differences in color, strength, hardness, density, elasticity, etc.

The first group, or destructive changes, are therefore, seen to be preliminary or preparatory for the final hardening or vitrification of the clay, and no clay can be satisfactorily vitrified until its minerals have been brought to a proper condition by this preparatory treatment. The preparatory process itself is divided into two stages called dehydration and oxidation. The former concerns itself with the expulsion of the combined water from the kaolinite and other hydrous minerals of the clay. The latter concerns itself with the burning out of the organic bodies, such as wood, leaves, grass, roots, peat, lignitic matter, coal graphite, bitumen, or oily matter, and with inorganic combustibles like sulphur from sulphides of iron and similar minerals, and also with the conversion of all oxides that are left in the clay mass into the state of equilibrium before mentioned, by giving up a part of their oxygen, or taking on more of it.

The dehydration and oxidation reactions are not differentiated from each other clearly in the time of their occurrence, but oxidation changes usually last the longest, and require a higher temperature to complete them, though some parts of the oxidation may begin as early or earlier than any of the dehydration changes.

Clays show a wide difference in behavior in the ease and completeness with which they undergo this preparatory treatment. Some clays contain almost no oxidizable matter, and are ready to go ahead for vitrification as soon as the water is well out of them. Such clays are very "easy" to handle. Others are so full of carbon, iron and sulphur compounds that they are actually combustible like low-grade fuels. Such require the most extreme care, and often specially designed kilns, to make it possible to produce marketable wares from them.

In general, clays show by change of color when they are through the oxidation period. The presence of carbon or sulphur is indicated in a partially burnt clay by a black or dark discoloration. When this disappears from the center of the ware, then it is known that these substances no longer remain in quantities sufficient to do further harm. At

the same time, the iron which up to this time may have been existing in unstable forms of blue, green, gray or yellow colors, now takes on the usual brick-red tint in common clays. In fire clays, where the iron is much less in quantity, the characteristic buff tint is produced. The loss of the center discolorations and the assumption of the oxidized iron color is evidence that the clay is prepared for vitrification.[1]

While the roofing tile manufacturer is usually little troubled by oxidation difficulties in his clay, owing to the extreme thinness of the ware and the consequent ease with which oxygen permeates the mass and does its work, and also the openness of the setting, by which the air secures easy contact with the wares, still it was thought advisable to conduct a careful experiment to show the extent to which the standard series of roofing tile clays do really offer oxidation difficulties, and thus obtain a basis for judging how far oxidation troubles should be allowed to weigh against a clay under consideration for this particular industry.

The cross section of ordinary roofing tiles being so thin, it was thought better to mould up the clays into test pieces of much thicker cross section, in order to require a longer treatment for oxidation and thus form a better opportunity to draw comparisons. All of the standard clays were passed through a 20-mesh screen, tempered and aged, as described earlier, and seven brickettes of each, two inches by two inches by four inches, were then made in the die box before described. At the center of each trial, on all four sides, a light indentation was made to assist in breaking the brickettes at the desired point after drawing from the kiln. The trials were all carefully dried, and were then set in a small down-draft test kiln, in such a manner that a complete set of all of the standard clays could be taken out at a single drawing. The firing was done by coke, with a large excess of air passing through the kiln. To better control the temperature, a pyrometer was used. Time and temperature observations were carefully made at intervals, and the curve shown in Figure 24 was drawn to indicate the progress of the heat treatment. As each draw was made, the trials were placed on the floor, and with chisel and hammer they were carefully broken apart along the indentation lines.

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[1]See in this connection:

Orton. The Role played by Iron in the Burning of Clays, Transactions American Ceramic Society, Vol. V, page 377.

Orton & Griffin. The Influence of Carbon in the Burning of Clay Wares. Bull; 2, National Brick Manufacturers' Association, Indianapolis, 1905.

Orton & Staley. The Status of Carbon Iron and Sulphur in Clays during the Various Stages of Burning; Bull. 3, National Brick Manufacturers' Association, Indianapolis, 1908.

Jackson & Hopwood. Trans. North Staffordshire Ceramic Soc. The Coloration of Clay Wares, 1902, p. 93.

Hopwood, A. Trans. English Ceramic Soc. The Changes in Color of Clays on Ignition in Clay Ware Kilns, 1903, p. 37.

In Figure No. 25, page 88, it will be observed that an attempt has been made to represent graphically the results of the experiment on the rate of oxidation of the standard roofing tile clays. The various trial pieces were numbered in the order in which they were drawn from the kiln. Corresponding numbers are placed at the foot of each column in Figure No. 25, as well as the duration of the burn in hours at the time of the draw. An effort has been made by shading to represent the intensity of the color of the unoxidized cores in the various trial pieces. For instance, clays F, I, A, B are shown with areas lightly shaded, while clays J, N, E, H are shown black, the shading approaching the depth of color intended in each case.

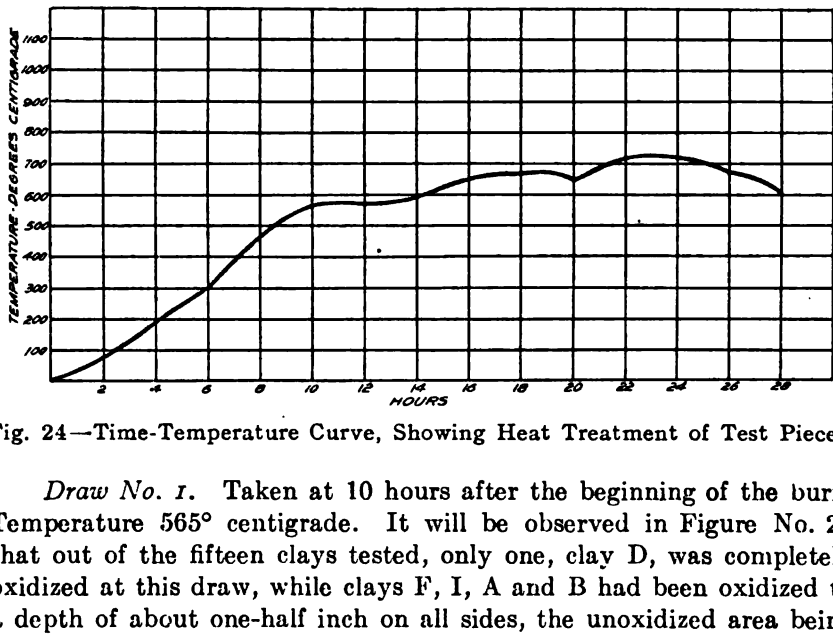


Fig. 24—Time-Temperature Curve, Showing Heat Treatment of Test Pieces.

Draw No. 1. Taken at 10 hours after the beginning of the burn. Temperature 565° centigrade. It will be observed in Figure No. 25 that out of the fifteen clays tested, only one, clay D, was completely oxidized at this draw, while clays F, I, A and B had been oxidized to a depth of about one-half inch on all sides, the unoxidized area being of a faint gray or blue-black color. At the same draw, clays K, M, O, L, G, C, J, and N had oxidized to a depth equal to or greater than F, I, A, and B, but the color of the unoxidized area was much darker, indicating a much larger amount of material to be oxidized. Clays E and H had only oxidized to a very shallow depth, less than one-fourth inch on all sides. In both of these cases, the central area was of a solid coal-black color.

Draw No. 2. Taken at 12 hours. Temperature 570° C.

Upon breaking open the trials from this draw, it was found that clays F and I had become completely oxidized, while clays A, B, K, M, O and G had an area of three-fourths inch to one inch in diameter still remaining unoxidized. Clays L, C, J and N contained areas of one inch to one and one-half inch in diameter still unoxidized, and in

clays E and H, the oxidation had proceeded but about one-eighth inch further in than it was in Draw No. 1.

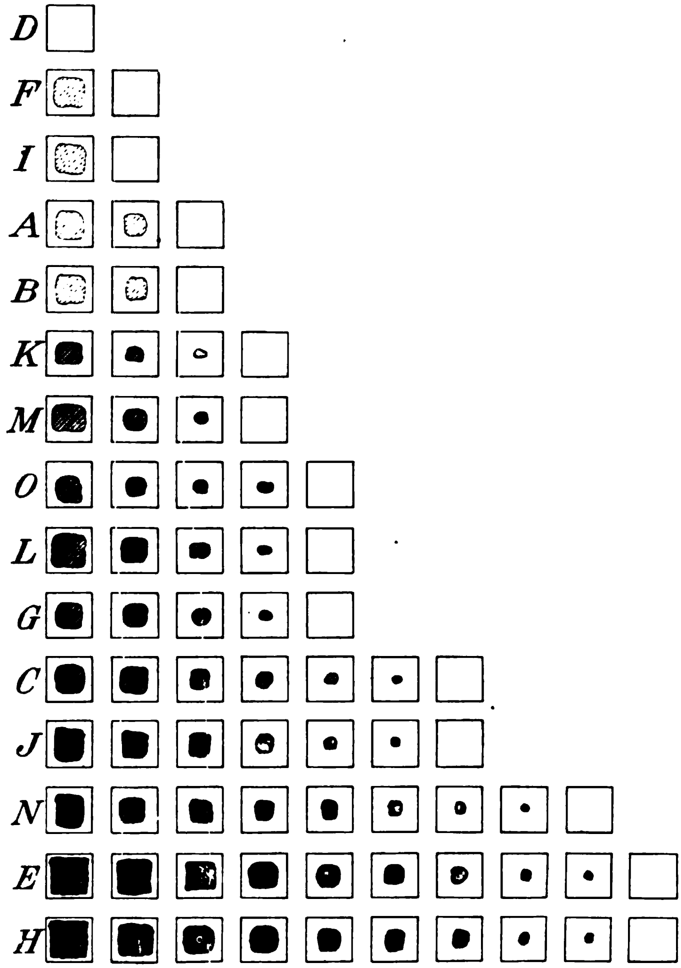


Fig. 25—Sketch Showing Progressive Oxidation of the Standard Roofing Tile Clays at Various Stages of the Burning Process.

Draw No. 3. Taken at 14¼ hours. Temperature 587° C.

Two more clays, A and B, had reached complete oxidation. Clays K, M and O only retained a small area unoxidized, about equal to the cross section of a lead pencil. In clays L, G, C, J and N, the oxidation had proceeded slightly less than in trials K, M and O, although all showed a marked change from draw No. 2. Clays J and N made the least gain. In clays E and H, the unoxidized portions had been reduced very little, but uniformly.

Draw No. 4. Taken at 15¼ hours. Temperature 620° C.

Two more clays, K and M, were found to have reached complete oxidation by the time of making this draw, while clays O, L, G and C retained but a very small area unoxidized. In clays J and N, the dark areas, while still darker than O, L, G and C, had undergone a marked decrease in size. The changes in clays E and H were noticeable, but small.

Draw No. 5. Taken at 20½ hours. Temperature 660° C.

Under the influence of the slightly increased temperature and the increased duration of time, clays O, L and G had reached complete oxidation, while N still contained a small area of black core. Clays E and H had lost their usual proportion of black area, but still contained a very dark core about three-fourths inch in diameter.

Draw No. 6. Taken at 24¾ hours. Temperature 730° C.

At this draw, trial-pieces C, J and N still retained a small area of core, not much reduced from that of No. 5. In trial pieces E and H, the core had only been reduced a very little, indicating that the oxidation in these clays was progressing very slowly, notwithstanding an increase of temperature and a time period of about 4 hours.

Draw No. 7. Taken at 28 hours. Temperature 605° C.

Observations at this draw showed trial pieces C and J to be complete in their oxidation, while the three clays N, E and H were still showing unoxidized areas about the size of a five-cent piece. Unfortunately the work could not be carried further, owing to the fact that only seven sets of trial pieces had been placed in the kiln. It had been thought that all of the clays would be completely oxidized at the end of a 24-hour period, and that seven draws would prove sufficient, but such was not the case. In order to complete the chart, the three clays N, E and H have been plotted as they would have appeared if the same rate of decrease of core had been maintained from there on to the finish as had been shown in the seven first draws. Using this same rate, and 4-hour intervals, clay N would have been completely oxidized at the end of 36 hours, while clays E and H would have taken 40 hours, provided the temperature had been held about constant.

Significance of this data.—Of the fifteen clays studied, only one clay, D, was found to be entirely free from unoxidized material at the end of 10 hours.

This clay in its natural condition is a deep-red or chocolate-colored shale, the color indicating that the iron present in the clay had been deposited in the ferric form, and that no carbon or reducing materials were deposited with it, to serve as a means of reducing it later.

In so far as oxidation is concerned, clay D, if made into roofing tiles, could be set tightly in the kiln, and fired fast, with no danger. It is the only clay of the series of which this could be said.

Clay A was oxidized in 12 hours. It is quite possible that the actual amount of material to be oxidized in this clay is as great as in

N, E and H, but the nature of the material is different. It is a shale whose structure is broken up by a high content of sandy material, making the body so porous that oxygen can readily permeate the tiles, and the carbonic acid generated can escape. N and H, on the other hand, are fine-grained alluvial deposits, and E a close-grained glacial clay. The fineness of grain in the three latter clays prevents the free permeation of the body by the oxygen, hence the oxidation period of the burn must be extended to properly provide for this.

Notwithstanding the fact that clay A was seemingly oxidized easily, it is known from actual use of this clay in the manufacture of shingle tiles that it gives trouble in the matter of center marks and black core, unless the burn progresses very slowly. Ten to twelve days are used in the proper burning of the tiles. The mode of setting the shingle tiles made from this clay is very dense and close and anything but conducive to easy oxidation or successful, rapid burning.

While it might appear, from the oxidation trials shown in this work, that much trouble might be expected in the burning of roofing tiles from such clays, such is not really the case. The fact that roofing tiles are thin wares, and that the shape of all tiles, excepting flat shingles, is such that tight setting is impossible, largely assists in the rapid oxidation of the tiles. The temperature at which this test was executed was also lower than necessary for safe oxidation, and the results were slower than in commercial practice on this account. However, oxidation at temperatures above 800° to 850° Centigrade has been shown by Orton[1] to be a common cause of different colored center-marks, even though all carbon and sulphur are finally expelled from the ware. In actual kiln firing, the oxidation begins at 350° or 400° and progresses till about 900°, at which point it seldom continues to make much headway. But in large kilns passing from 400° to 900° it usually stands for considerable time-periods, 24 to 48 hours or more, and this test shows that even in wares two inches square, not more than 40 hours would be required.

It was not the purpose in making this test to try to establish a definite time for the oxidation period of any clay. In a search of ceramic literature for data, nothing could be found that would enable one to make safe conclusions upon the relative speed of oxidation in trial pieces and full-sized wares, and no attempt has been made to do so in this discussion. It is clear, however, from the work done, that clays like E and H will take very much more time than A or B, and that roofing tiles, while easy to oxidize as a class, are nevertheless not at all exempt from troubles in this connection.

An interesting point has been brought out in this work, in the study of the three clays, I, K and J taken singly, and the mixture L, formed by their blend. It will be observed that I shows very little

[1]See references cited on page 86.

trouble in oxidizing, K a little more, and J very much more: in fact, the latter clay would be considered bad. The mixture of these three clays in the proportions used by the company furnishing them is an improvement over J, but is worse than K alone, and very much worse than I, which by itself would be considered as a good or easy clay to oxidize. This company is thus taking a very easily oxidizable clay and by adding others to it is greatly increasing the danger of getting black-cored and center-marked ware. So far as oxidation alone is considered, it would be better to discard J entirely, and K if possible.

VITRIFICATION RANGE.

General Discussion.—As explained under oxidation behavior, the changes occurring in the second part of the burn are constructive in nature, as a body is produced having physical properties entirely different from those of the original material as a whole or of its component minerals. The burned clay is a partially fused silicate mass—the extent to which the fusion has gone depending on the length and temperature of the firing, the mineral mixture present, the fineness of grain of these minerals, the completeness of their oxidation treatment, and many other factors.

All clays, in producing marketable goods, must pass through some of this constructive heat work—how much, depends on the kind of product sought. But while practically all clays must undergo such a change, the rate at which the change takes place varies very greatly and constitutes one of the important criteria in deciding on the suitability of clays for use. The difference between clays in this respect ranges from those which harden, shrink, and reach their best structure interval of 50° centigrade in a few hours' time, to others which require 300° or even 400° centigrade and several days' time to bring about the desired degree of combination. Without going, at this place, into any discussion of the causes of these wide differences, it is desired to know what the fusion habit of each of the standard series of roofing-tile clays is, with a view to interpreting the suitability of other clays for this purpose.

A wide or gradual vitrification range has usually been considered as of more importance for roofing tiles than for most clay products, because quick or sudden vitrification is usually associated with rapid and excessive changes in volume, with warpage and deformation, with rolling or falling over in the kiln, etc., and these difficulties are all extra severe on wares of large area and thin cross section, like roofing tile.

The determination of the vitrification range of a clay can most conveniently be done by firing a series of test pieces of suitable shape and size through a series of increasing temperatures, withdrawing one or more at each successive temperature stage, and measuring their various resultant physical properties. By the progressive change in these properties, especially in the color, hardness, porosity, specific

gravity, and shrinkage, the progress of the fusion reactions may be approximated.

It will at once be appreciated that a thorough study of the vitrification range involves or constitutes a thorough study of the final physical properties which the clay takes on by burning. These various properties, such as hardness, porosity, specific gravity, strength, color etc., are inherent properties of the clay, or latent within it, and they furnish a large share of the evidence in deciding the fitness of the clay for any purpose. So that we wish to know, not only the *rate* at which these properties develop in burning and the temperature range needed to draw them out, but we also need to know what the final status of the burnt clay is in each of these various respects. For instance, a clay may be shown to have a wide and perfectly satisfactory vitrification range, but its hardness, strength, color, etc., may be wholly unsatisfactory from the standpoint of producing a commercial product notwithstanding.

Therefore, in the following studies made on the test pieces drawn progressively from the kiln as the temperature rose, the two points of view will be preserved and considered separately.

The trial pieces chosen for burning for this test were the same as had been used in determining the drying shrinkage, viz., bars one inch by one inch by four and one-half inches, made on a small hand-power plunger machine. There were ten trial pieces of each clay, carefully marked with the sample letter, and numbered 1 to 10, inclusive. Each bar was also stamped with marks one hundred millimeters apart on the plastic clay; these marks came closer together as the clay shrank. In setting these trial pieces for burning, the pieces marked No. 1 of each clay were placed together, the No. 2's and each following number being similarly assembled. Each lot was placed in a convenient position for drawing. The firing was done in a Caulkin's Revelation kiln, fired by natural gas. With each lot of trial pieces was placed a standard pyrometric cone at the fall of which it was desired to draw the lot, as follows:

No. 1	Cone 010	No. 6	Cone 1
No. 2	Cone 08	No. 7	Cone 2
No. 3	Cone 06	No. 8	Cone 3
No. 4	Cone 04	No. 9	Cone 4
No. 5	Cone 02	No. 10	Cone 5

Thus, when cone 010 melted, all of the trial pieces No. 1 were drawn; at cone 08 all of the trial pieces No. 2, and so on. To prevent the trial pieces from cracking by cooling suddenly in the air, and to better develop the color, a small up-draft kiln standing near the Caulkin's kiln was fired up to a good red heat and kept in that condition. The trial pieces as drawn from the test-kiln at the specified cone-temperatures were quickly transferred to the up-draft kiln. When the entire ten lots had been

transferred, the kiln was allowed to cool gradually down to the atmospheric temperature. This precaution is highly necessary, if a normal color or strength is to be obtained.

On these ten lots of trial pieces, the following properties were studied and measured:

1—Color.	4—Specific gravity.
2—Hardness.	5—Shrinkage.
3—Porosity.	6—Warpage and deformation.

Color.—A good, clean, attractive color is a *sine qua non* with a successful roofing tile. If the material does not burn to a good, clean color in itself, the use of a slip of clay or engobe, or some body-colorant, must be used.

In this country at the present time, only one natural color is really available for roofing tiles, and that is red. From time to time in the past years, a few tiles have been made up from buff burning-clays, but the demand for them has been very meager, and their manufacture soon abandoned.

Of twelve plants inspected in 1908, eight were producing tiles of good red color from natural clays or shales, without the use of slips, engobes, or admixed mineral colors. The ninth and tenth plants were using a red-burning slip-clay to mask the poor color obtained from the raw material in use.

The eleventh plant was using a slip clay, but with a very different object in view. Their raw material in itself burns to a very nice red color, but, according to the statement of those in charge, it is rough and pimply. The slip is used to improve the surface finish of the tiles, so that they will remain bright and clean after being put in position on the roof. The above claim is probably well founded, in their particular case at least, for the following reasons:

The tiles at this plant are pressed on plaster dies. In the nature of the case it is impossible to keep the surface of a plaster die in perfect condition. It soon becomes badly pitted with minute pores or open cells, so that the tiles made upon it receive the reverse impression of the pitted die surface, producing very rough, pimpled surfaces.

If such tiles are soft or medium burned, they will, when placed upon the roof, very easily catch dust and dirt, becoming black and begrimed within a very short time. Had these same tiles been coated with a good slip, their roughness would have been largely obliterated by the slip filling up the minute cavities on the surface of the tiles.

In the burning at the above plant it is the practice to stop at a point considerably below complete vitrification, or in other words to leave the tiles still quite porous. Hence, upon placing them upon the roof, it would be natural to expect them to take up much dirt and become badly discolored. Thus, it is possible, by using a slip clay which vit-

rifies at an early period, to coat the tile-body with a vitrified covering, which will act much like a glaze. The product, instead of becoming weather beaten and dirty, will remain bright and clean by being washed with each rain.

If the above clay would stand a higher degree of vitrification than is at present given it, then the slipping of the tile would no longer be justifiable, owing to the extra cost and the loss by breakage during the operation. Should it be found that the clay, upon a higher vitrification, deformed very badly, then the present procedure of low-temperature burning, with the use of a good perfect-fitting slip clay, would be justified as the best method of handling a troublesome clay.

At the twelfth plant, a very different method is pursued to improve or change the color of the tile for special orders. A few per cent. of mineral-red (oxide of iron) is added to the clay as it is being pugged, thus mixing the colorant through and through the clay.

While the addition of the oxide darkens the natural color of the clay very materially, it was hard to see where it had improved the natural red color. It gave a dull or faded appearance to the tile thus treated. It has been repeatedly demonstrated, practically and experimentally, that it is impossible to obtain good, red colors by doctoring the clay with a free oxide of iron. This instance merely adds one more to the list of failures.

In taking up the study of the colors produced in this research it must be borne in mind that it is impossible to make any clay give its best color, when fired in small test-kilns, and cooled rapidly. From a previous knowledge of the colors obtained commercially from each of the standard clays tested, it was observed that the colors obtained with test-kiln burns check those obtained in the regular way very closely, with the exception that the colors are not so bright or clear.

While the terms used to characterize the various shades used in describing these results have a wide latitude, it has been the endeavor to use them consistently in the series. These data have been arranged in Table 12, pages 95, 96, 97, 98, 99 and 100. It has also been thought worth while to include a column giving the percentage porosity of each trial piece in order to better associate the colors developed with the progress of the vitrification reaction.

Additional Color Trial.—A further study on the color of the various clays has been taken from the warpage trial pieces. These trial pieces were burned in a coke-fired kiln, under conditions which would more nearly approach the commercial than those of the vitrification test burn, in which the firing was by gas and the trial pieces were drawn from the kiln at the cone indicated. Although immediately transferred to a hot kiln for gradual cooling, still such conditions are not conducive to the production of the best colors which a clay is able to produce. The

TABLE No. 12.

Color Studies on Standard Roofing Tile Clays.

CLAY A

Drawn at Cone.	Colots Found on Cooling.	Percentage Porosity.
010	Light yellow-red	29.53
08	Slightly darker	25.77
06	Slightly darker than at cone 08	18.11
04	Deep red—A commercial color	11.52
02	Much darker red—A commercial color	7.48
1	Very dark red—A commercial color	4.95
2	Very dark red, bordering on brown	3.00
3	Chocolate brown	2.51
4	Chocolate brown (dark)	1.08
5	Blue black	1.25
	This clay gives its best color range from cone 04 to 02.	

CLAY B.

Drawn at Cone.	Colors Found on Cooling.	Percentage Porosity.
010	Very light yellowish red	31.07
08	Slightly darker red	31.12
06	Light red —A commercial color	26.80
04	Better red than 06—A commercial color	25.76
02	Same as 04—A commercial color	26.15
1	About two shades darker red—A commercial color	21.95
2	Dark red brown	19.29
3	Chocolate brown	12.57
4	Dark chocolate brown	14.04
5	Blue black	3.12
	This clay gives its best color range from cones 04 to 1.	

CLAY C.

Drawn at Cone.	Colors Found on Cooling.	Percentage Porosity.
010	Salmon-yellow	35.94
08	Slightly darker	35.02
06	Same	32.45
04	Much darker, through still a light red	17.00
02	Very good red—A commercial color	14.30
1	Dark red—A commercial color	7.41
2	Very dark red—A commercial color	5.22
3	Chocolate brown (light) —A commercial color	4.07
4	Chocolate brown (dark)	1.10
5	Bluish brown	....
	This clay gives its best color range from cone 02 to 1.	

TABLE No. 12—Continued.

Color Studies on Standard Roofing Tile Clays.

CLAY D.

Drawn at Cone.	Colors Found on Cooling.	Percentage Porosity.
010	Light red	32.85
08	Same	32.03
06	Yellowish red	33.29
04	Much darker red—A commercial color	24.59
02	Cherry red—A commercial color	13.04
1	Dark brownish red—A commercial color	12.62
2	Darker brownish red—A commercial color	10.12
3	Very dark brown-red—A commercial color	2.62
4	Bluish brown	0.74
5	Green	0.80
	This clay gives its best color range from cones 04 to 02.	

CLAY E.

010	Light pinkish red	38.42
08	Very light salmon	39.87
06	Same	39.34
04	Same	41.67
02	Same	40.10
1	Buff specks in a matrix of reddish buff	12.50
2	Same	26.24
3	Buff specks in a matrix of brown	1.90
4	Bluish or gray	2.72
5	Same	1.60
	There were no commercial colors developed. This clay would have to be slipped.	

CLAY F.

010	Light pinkish red	33.99
08	Somewhat darker, though still too light	31.83
06	Same	33.48
04	Light red, rather yellowish	23.65
02	Same	24.61
1	Dark brown	12.08
2	Dark brown	16.83
3	Very dark brown	2.93
4	Bluish	0.60
5	Same	1.24
	The nearest approach to commercial colors are obtained at cones 04 to 02. These colors are not good when compared to the standard tiles on the market. This clay should be slipped.	

TABLE No. 12—Continued.

Color Studies on Standard Roofing Tile Clays.

CLAY G.

Drawn at Cone.	Colors Found on Cooling.	Percentage Porosity.
010	Very light red, almost buff	28.31
08	Same	27.73
06	Much darker red	19.03
04	A shade darker, much better—A commercial color	16.19
02	Same—A commercial color	16.69
1	Dark red—A commercial color	8.22
2	Dark red-brown	9.10
3	Same	8.77
4	Same	8.42
5	Dark brown	7.82
	This clay gave its best color range at cones 04-02.	

CLAY H.

Drawn at Cone.	Colors Found on Cooling.	Percentage Porosity.
010	Light brick red	30.76
08	Same	24.88
06	Same	29.94
04	Much darker red—A commercial color	24.95
02	Same—A commercial color	25.37
1	Chocolate-red (light)—A commercial color	8.05
2	Chocolate-red (dark)—A commercial color	16.20
3	Very dark chocolate	1.65
4	Blue	2.56
5	Same	1.97
	This clay gave its best color range at cone 04-02.	

CLAY I.

Drawn at Cone.	Colors Found on Cooling.	Percentage Porosity.
010	Light yellowish red	33.04
08	Same, though a little deeper	33.33
06	Poor red with yellow specks	32.10
04	Same	32.17
02	Same	32.10
1	Darker, poor color, yellow specks	29.62
2	Chocolate matrix, yellow specks	23.88
3	Same	17.94
4	Same	15.32
5	Nearly black matrix, yellow specks	0.52
	At no point does this clay show a good color. It is best at cone 08.	

TABLE No. 12—Continued.

Color Studies on Standard Roofing Tile Clays.

CLAY J.

Drawn at Cone.	Colors Found on Cooling	Percentage Porosity.
010	Very light pink tinted buff	24.55
08	Same	22.98
06	Light yellowish brown or tan	11.22
04	Same	9.30
02	Same	9.15
1	Same	7.41
2	Olive green brown or tan	7.17
3	Same	7.40
4	Same	7.88
5	Light tan color	9.21
	There were no good colors developed by this clay. It would require slipping.	

CLAY K.

Drawn at Cone.	Colors Found on Cooling	Percentage Porosity.
010	Yellowish red. Not commercial	17.53
08	Darker yellowish red. Not commercial	14.48
06	Much darker red. Commercial	8.24
04	Deep red. Commercial	5.77
02	Deep red. Some flash. Commercial	1.71
1	Same	0.65
2	Same	0.80
3	Overfired	....
4	Overfired	....
5	Overfired	....

CLAY L.

Drawn at Cone.	Colors Found on Cooling	Percentage Porosity.
010	Light brick red	27.26
08	A shade darker, but still a poor red	24.82
06	Improved but still yellowish red—A commercial color	22.59
04	Darker red, but dull or dead—A commercial color	18.35
02	Same—A commercial color	15.50
1	A very little darker—A commercial color	15.63
2	Chocolate-brown, poor color	12.76
3	Same, but darker	10.55
4	Melted	5.20
5	Melted	4.45
	While there are a number of colors in this set which are reported as commercial, they are not very good, having too much of a yellow tint. Clay L is the mixture of clays I, J and K, as used in actual tile manufacture.	

TABLE No. 12—Concluded.

Color Studies on Standard Roofing Tile Clays.

CLAY M.

Drawn at Cone.	Colors Found on Cooling	Percentage Porosity.
010	Very light brick red	29.88
08	Light brick red	29.42
06	Much deeper red—A commercial color	28.49
04	Same—A commercial color	28.73
02	A shade darker—A commercial color	27.74
1	Much deeper red, rather dull—A commercial color	21.73
2	Chocolate-brown	10.73
3	Same	3.66
4	A very little darker	3.10
5	Same, but dead color	0.51
	This clay gives its best color at cones 06-02.	

CLAY N.

010	Very light red	37.12
08	Same	38.25
06	Gray buff	37.64
04	Same	37.20
02	Same	36.42
1	Darker gray	18.25
2	Same	17.86
3	Dark gray	5.68
4	Same	21.04
5	Yellow-brown (trial melted)	1.01
	There were no commercial colors in this set of trials. A slip clay would have to be used.	

CLAY O.

010	Light salmon yellow	27.31
08	Same	32.23
06	Slightly darker	29.04
04	A little darker red	22.85
02	Medium red color. A commercial grade	20.04
1	Drak red color. A commercial grade	8.84
2	Same. A commercial grade	11.74
3	Chocolate-red. Almost too dark	7.31
4	Same	3.92
5	Blue	5.35

trial pieces about to be studied were burned and cooled in the same kiln, hence giving better conditions for a normal color.

Clays A and B give their best commercial colors between cones 07 and 04.

Clays C gave its best colors at a little higher temperature, namely, cones 04 to 01. This clay scummed badly.

Clay D produced its best color at cones 04 to 01, though a fair light red is obtained at cones 09 to 07.

Clay E produced nothing but buff-colored trials, due to the lime present in the clay. These trials also show considerable popping from limestone.

Clay F gave its best red at cone 07, though the color is poor. All trial pieces of this clay were covered with scum or whitewash.

Clay G has a range of good color extending from cones 07 to 01, with .04 as the best point.

Clay H produces its best color from cones 07 to 04, with 07 as the best color. This clay developed numerous limestone pops, which would be strongly against it commercially.

Clay I is fairly good in color from cone 07 to 01, with trial pieces at cone 07 as the best.

Clay J did not produce any good colors, and furthermore the trial pieces were all coated with a scum.

Clay K in this burn has given commercial colors from cones 09 to 04, with the 07 and 04 trial pieces the best.

Clay M gives good commercial colors at cones 07 to 01, but is badly discolored with scum.

Clay N is pink at cone 09, but all the balance of the trial pieces are buff, due to its large lime content. These trial pieces are, in addition to their poor color, scummed and lime-popped.

Summing up the results of the entire series, clays A, B, C, D, G and M have given the best results. Clays H, K and I have given fairly good results, the colors being too light a red, or yellowish. Clays E, F and N would have to be given a coat of slip clay in order to make them commercial.

A closer grading of the colors obtained in this work would give first place to clays A, B and D.

From the foregoing, Table No. 13 has been abstracted.

TABLE No. 13.

Summary of Color Studies on the Standard Roofing Tile Clays.

Designation of Clay.	Color Range.
A	Deep red, commercial grade—Cone 04–1.
B	Fine red, commercial grade—Cone 06–1.
C	Good red, commercial grade—Cone 02–3.
D	Good red, commercial grade—Cone 04–3.
E	Pink, salmon, buff, brown and blue-gray. Full of specks. Requires slip.
F	Pink, light red, brown and blue, with non-commercial red. Requires slip.
G	Good red, commercial grade—Cone 04 to 1.
H	Good red, commercial grade—Cone 04–2.
I	Yellowish red, poor red, chocolate and black. Not a good commercial grade. Requires slip.
J	Pinkish, buff, tan, brown and olive green. Would require slip.
K	Good red, commercial grade—Cone 06–2.
L	Poor lifeless red, barely commercial—Cone 06–1.
M	Good red, commercial grade—Cone 06–1.
N	Light red, buff, gray and yellow-brown. Would require slipping.
O	Good red, commercial grade—Cone 02–2.

It is somewhat astonishing to find that of twelve roofing tile plants, only eight were found to be working on good, clean, handsome, red-burning material. Three were working calcareous clays, which pass through a long cycle of color changes, without at any stage making a commercial red, and one plant mixes a clay of good, red-burning color, with two others, neither of which can pass muster, and the mixture resulting is a poor, lifeless, barely commercial red.

This is only another illustration of a fact well known in the clay industry, viz., that many plants are started by persons of little or no experience, and without expert advice, and after making heavy investments they find their clays unsuitable. Such concerns usually fail for their first projectors, but after one or more forced sales, at constantly reduced valuations, they ultimately fall into capable hands and are operated. The handicap of a poor or mediocre material remains, however, and is a constant bar to a really high grade product, or large financial success.

Color Range vs. Vitrification Range.—A study of the vitrification range, as disclosed by the color changes, gives the following data:

TABLE No. 14.

Comparison Between Color Range and Vitrification Range.

Designation of Clay.	End of immaturity.	Period of maturity.	Period of overmaturity of color. Body still sound.	Point at which color goes black, and body fails also.	Remarks.
A	Cone 06..	Cone 04–1.	Cone 2–4.	Cone 5...	A fairly wide range.
B	Cone 08..	Cone 06–1.	Cone 2–4.	Cone 5...	A wide range.
C	Cone 04..	Cone 02–3.	Cone 4...	Cone 5...	A good range.
D	Cone 06..	Cone 04–3.	Cone 4...	Cone 5...	A good range.
E	Cone 02..	Cone 1–3.	Cone 4...	Not reached	Narrow range.
F	Cone 06..	Cone 04–02	Cone 1...	Cone 4...	Narrow range.
G	Cone 06..	Cone 04–1.	Cone 2–5.	Not reached	A fairly wide range.
H	Cone 06..	Cone 04–2.	Cone 3...	Cone 4...	A good range.
I	Cone 010.	Cone 08...	Cone 1–4.	Cone 5...	A wide range.
J	Cone 08..	Cone 06–1.	Cone 2–4.	Cone 5...	A wide range.
K	Cone 08..	Cone 06–2.	....	Cone 3...	A wide range.
L	Cone 08..	Cone 06-1.	Cone 2-3	Cone 4...	A good range.
M	Cone 07..	Cone 06-1.	Cone 2-5.	Not reached	A wide range.
N	Cone 08..	Cone 06–3.	Cone 3 4.	Cone 5...	A wide range.
O	Cone 04..	Cone 02-2.	Cone 3-4	Cone 5...	Fair range

The foregoing table gives an illuminating view of roofing tile clays, and their variations, and enables us to fix a sort of tentative type for the group. So far as color changes are competent to decide, the type clay is as follows:

TABLE No. 15.

Color Scale of Typical Roofing Clay.

TINTS.	Range in Cones.
Immature and light red colors—Up to Cone 06	....
Commercial-red Color Range—Cone 05 to Cone 1	5 Cones
Overmature Colors, red or brown, with body still sound—Cone 2 to Cone 4	3 Cones
Blue or Black Colors, with failure of body as well—Cone 5 and above	....

The behavior of the four undesirable clays (not considering I, J, and K, which are not used individually in any plant and which appear in their proper proportions in Sample L) is difficult to summarize, because

they fail in a variety of ways. The foundation of the trouble of all, however, is the presence of enough lime to destroy or injure the red color.

Hardness.—The idea of hardness in the minds of most clay workers is associated with other concurrent physical properties which, strictly speaking, are not the same thing, though intimately related. The property of physical strength is involved in this common conception, and also the factor of toughness or brittleness. A clay worker in speaking of a tile would call it "too hard," without really meaning that the hardness itself is undesirable, but merely that its hardness leads him to expect it to be too brittle, and it is this quality he has in mind in condemning it.

Toughness, or its converse, brittleness, is a property not easily measured, except by rough comparative tests, such as the rattler test. As roofing tiles are never subjected in actual use to any influences tending to wear them out by friction or grinding, nor normally to impacts or blows, the application of the rattler test to this ware seems very foreign and inappropriate. Tests for hardness, as distinct from toughness or ability to resist blows, based on grinding the ware away by an abrasive plate or disc, under fixed conditions of pressure, lubrication with water, etc., have been proposed and carried out a few times by various investigators, but no standardized form of this test has come into acceptance.

The simplest, oldest and most universally practiced gauge of hardness is the cutting test—a mode so crude as to be practically impossible to standardize it, but so simple that, *for any one person*, its findings soon become satisfactory and convincing to himself. Nothing is required but a piece of hard steel, a knife or file, or similar tool, ground to a sharp but not thin edge. A triangular file, with all three surfaces ground into planes, makes the best tool. With this steel tempered as hard as it can be gotten, a man can soon gauge hardness in burnt clay wares, in terms that are not translatable into figures, but which are nevertheless satisfactory.

The test as carried out in this work was done by taking a sharp piece of file steel in the hand, as one would hold a glass cutter. Then with varying degrees of pressure from the hand, the tiles were easily scratched, barely scratched, or not scratched at all, or the steel left a blue metallic mark on the tile's surface. In the latter case, the tiles were classified as being harder than steel. Other trial pieces that could not be scratched, but failed to give a blue steel mark, were classified as steel-hard. After a little practice, these gradations could be determined without much difficulty.

In the following table, No. 16, is shown the data concerning the hardness of a series of samples of commercial roofiing tiles. In connection with the hardness, the percentage absorption is also shown:

TABLE No. 16.

Showing the Hardness of Some Commercial Tiles.

Designation of Sample.	Description of Resistance to Cutting.	Character of Fracture.	Percentage Absorption in 48 Hours.
A-1	Difficult to scratch	Stony	12.13
A-2	Difficult to scratch	Stony	13.89
B-1	Very difficult to scratch	Stony	6.22
B-2	Easily scratched	Porous and stony	20.03
B-3	Very difficult to scratch	Stony	8.43
B-4	Easily scratched	Porous and stony	20.63
C-1	Easily scratched	Stony	17.72
C-2	Easily scratched	Stony	13.35
D-1	Very difficult to scratch	Stony	5.82
D-2	Equal to steel	Semi-vitreous	3.26
E-1	Very difficult to scratch	Stony	5.92
F-1	Harder than steel	Vitreous	0.80
F-2	Equal to steel	Semi-vitreous	2.24
G-1	Equal to steel (Buff tile)	Stony	2.31
G-2	Harder than steel	Stony	1.73
H-1	Equal to steel (Buff tile)	Stony	7.61

In the following table, No. 17, pages 105-108, are shown the data on hardness as obtained from the experiments made on the standard roofing tile clays in the laboratory. They do not represent commercial wares:

TABLE No. 17.

Showing Comparative Hardness of Trial-pieces of the Standard Roofing Tile Clays.

CLAY A.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Easily scratched	010	Open, stony	29.53
2	Slightly harder than A-1	08	Dry, stony	25.77
3	Slightly harder than A-2	06	Dry, stony	18.11
4	Equal to steel	04	Semi-vitreous	11.52
5	Harder than steel } Best colors.	{ 02	Semi-vitreous	7.48
6	Harder than steel } Best colors.	{ 1	Semi-vitreous	4.95
7	Harder than steel	2	Semi-vitreous	3.00
8	Harder than steel	3	Semi-vitreous	2.51
9	Harder than steel	4	Semi-vitreous	1.08
10	Harder than steel (overfired)	5	Stony	1.23

CLAY B.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Scratched easily	010	Open grained	31.07
2	Scratched easily	08	Open grained	31.12
3	Difficult to scratch (Com. color)	06	Dry and stony	26.80
4	Very difficult to scratch	04	Dry and stony	25.76
5	Very difficult to scratch	02	Dry and stony	26.15
6	Barely possible to scratch	1	Stony	21.95
7	Equal to steel	2	Stony, very dense	19.29
8	Steel hard	3	Stony, very dense	12.57
9	Harder than steel	4	Vitreous	14.04
10	Harder than steel	5	Semi-vitreous	3.12

CLAY C.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Scratched very easily	010	Very open grained	35.94
2	Scratched very easily	08	Very open grained	35.02
3	Slightly harder	06	Very open grained	32.45
4	Difficult to scratch (Com. color)	04	Open, stony	17.00
5	Equal to steel	02	Dense, stony	14.30
6	Harder than steel	1	Semi-vitreous	7.41
7	Harder than steel	2	Vitreous	5.22
8	Harder than steel	3	Glassy	4.07
9	Harder than steel	4	Glassy	1.10
10	Harder than steel (overfired)	5	Stony	0.98

TABLE No. 17—Continued;

Showing Comparative Hardness of Trial-pieces of the Standard Roofing Tile Clays.

CLAY D.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Scratched very easily	010	Open grained	32.85
2	Scratched very easily	08	Open grained	32.03
3	Scratched very easily	06	Open grained	33.29
4	Difficult to scratch (good color)	04	Dense, stony	24.59
5	Nearly equal to steel (best color)	02	Semi-vitreous	13.04
6	Harder than steel (good color)	1	Semi-vitreous	12.62
7	Harder than steel	2	Semi-vitreous	10.12
8	Harder than steel	3	Semi-vitreous	2.62
9	Harder than steel (overfired)	4	Stony	0.74
10	Harder than steel (overfired)	5	Stony	0.80

CLAY E.

1	Scratched easily	010	Open grained	38.42
2	Slightly harder	08	Open grained	39.87
3	Slightly harder	06	Open grained	39.34
4	Slightly harder	04	Little more dense	41.67
5	Slightly harder	02	Little more dense	40.10
6	Equal to steel	1	Stony	12.50
7	Trifle under steel hard	2	Strong, but open	26.24
8	Harder than steel	3	Vitreous	1.90
9	Harder than steel	4	Vitreous	2.72
10	Harder than steel (overfired)	5	Stony	1.60

CLAY F.

1	Very easily scratched	010	Very open grained	33.99
2	Much harder	08	Very open grained	31.83
3	Much harder	06	Very open grained	33.48
4	Difficult to scratch	04	Dense, stony	23.65
5	Difficult to scratch	02	Dense, stony	24.61
6	Harder than steel	1	Vitreous	12.08
7	Harder than steel	2	Semi-vitreous	16.83
8	Harder than steel	3	Vitreous	2.93
9	Harder than steel (overfired)	4	Stony	0.60
10	Harder than steel (overfired)	5	Stony	1.24

CLAY G.

1	Very easily scratched	010	Very open grained	28.31
2	Very easily scratched	08	Very open grained	27.73
3	Nearly equal to steel (good color)	06	Stony	19.03
4	Nearly equal to steel } best color	04	Stony	16.19
5	Nearly equal to steel } best color	02	Stony	8.22
6	Harder than steel } best color	1	Semi-vitreous	9.10
7	Harder than steel	2	Vitreous	8.77
8	Harder than steel	3	Vitreous	8.42
9	Harder than steel	4	Vitreous	8.42
10	Harder than steel	5	Stony	7.82

TABLE No. 17—Continued.

Showing Comparative Hardness of Trial-pieces of the Standard Roofing Tile Clays.

CLAY H.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Easily scratched	010	Very open grained	30.96
2	Slightly harder	08	Very open grained	24.88
3	Same	06	Very open grained	29.94
4	Difficult to scratch (good color)	04	Dense, stony	24.95
5	Difficult to scratch (good color)	02	Dense, stony	25.37
6	Harder than steel, too dark	1	Semi-vitreous	8.03
7	Harder than steel, too dark	2	Semi-vitreous	16.20
8	Harder than steel, too dark	3	Vitreous	1.63
9	Harder than steel (overfired)	4	Stony	2.56
10	Harder than steel (overfired)	5	Stony	1 97

CLAY I.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Difficult to scratch	010	Open, stony	33.04
2	Difficult to scratch (best color)	08	Open, stony	33.33
3	Very difficult to scratch	06	Stony	32.10
4	Very difficult to scratch	04	Stony	32.17
5	Very difficult to scratch	02	Stony	32.10
6	Nearly equal to steel	1	Stony	29.62
7	Equal to steel	2	Stony	23.88
8	Steel hard	3	Semi-vitreous	17.94
9	Steel hard	4	Semi-vitreous	15.32
10	Steel hard (overfired)	5	Stony	0.52

CLAY J.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Difficult to scratch	010	Open grained	24.55
2	Difficult to scratch	08	Open grained	22.98
3	Nearly equal to steel } best color	06	Stony	11.22
4	Equal to steel } best color	04	Semi-vitreous	9.30
5	Equal to steel } best color	02	Semi-vitreous	9.15
6	Harder than steel	1	Vitreous	7.41
7	Harder than steel	2	Vitreous	7.17
8	Harder than steel	3	Vitreous	7.40
9	Harder than steel	4	Vitreous	7.88
10	Harder than steel (overfired)	5	Stony	9.21

CLAY K.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Difficult to scratch	010	Dry, earthy fracture	17.53
2	Difficult to scratch	08	Stony	14.48
3	Barely possible to scratch	06	Stony	8.24
4	Harder than steel	04	Semi-vitreous	5.77
5	Harder than steel	02	Vitreous	1.71
6	Harder than steel	1	Vitreous	0.65
7	Harder than steel	2	Semi-vitreous	0.80
8	Overfired	3	Spongy	......
9	Overfired	4	Spongy	......
10	Overfired	5	Spongy	......

TABLE No. 17—Concluded.

Showing Comparative Hardness of Trial-pieces of the Standard Roofing Tile Clays.

CLAY L.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Difficult to scratch	010	Stony, open grained	27.26
2	Difficult to scratch	08	Stony, open grained	24.82
3	Very difficult to scratch	06	Stony, open grained	22.59
4	Nearly equal to steel } best color	04	Stony, more dense	18.35
5	Nearly equal to steel } best color	02	Stony, more dense	15.50
6	Steel hard	1	Vitreous	15.63
7	Harder than steel	2	Vitreous	12.76
8	Harder than steel	3	Vitreous	10.55
9	Overburned	4	Stony	5.20
10	Overburned	5	Stony	4.45

CLAY M.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Easily scratched	010	Stony, open grained	29.88
2	Easily scratched	08	Stony, open grained	29.42
3	Difficult to scratch	06	Stony, more dense	28.49
4	Difficult to scratch	04	Stony, more dense	28.73
5	Difficult to scratch	02	Stony, more dense	27.74
6	Nearly equal to steel (best color)	1	Stony	21.73
7	Harder than steel	2	Glassy	10.73
8	Harder than steel	3	Vitreous	3.66
9	Harder than steel	4	Vitreous	3.10
10	Harder than steel	5	Stony	0.51

CLAY N.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Easily scratched	010	Open grained	37.12
2	Easily scratched	08	Open grained	38.25
3	Slightly harder	06	More dense	37.64
4	Same	04	Same	37.20
5	Same	02	Same	36.42
6	Nearly equal to steel	1	Stony	18.25
7	Nearly equal to steel	2	Stony	17.86
8	Harder than steel	3	Stony	5.68
9	Nearly equal to steel	4	Stony	21.04
10	Melted	5	Slaggy	1.01

CLAY O.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Easily scratched	010	Open grained	......
2	Slightly harder	08	Open grained	......
3	Much harder	06	Open grained	......
4	Difficult to scratch	04	Becoming dense	......
5	Very difficult to scratch	02	Very dense, but dry	......
6	Equal to steel } best colors	1	Stony	......
7	Equal to steel } best colors	2	Stony	......
8	Harder than steel	3	Semi-vitreous	......
9	Harder than steel	4	Semi-vitreous	......
10	Harder than steel	5	Stony	......

In order to obtain some judgment as to what degree of hardness in the foregoing tables represents a satisfactory roofing tile structure, we must be guided by the following considerations:

A tile should have a hardness sufficient to make it easily handled and shipped without chipping or easy breakage, and above all to resist any damage from frost. But a tile burned to a degree of extreme hardness is just as much at fault as one too soft-burned. In the former case, the tile has been carried to a degree of vitrification where it becomes vitreous and is brittle, and will withstand handling, shipping, and cutting at the roof very poorly and large losses will result. Also, what has been said earlier in this report under the heading of "Porous vs. Vitrified Tile" applies to the hardness also. That is, a tile that has been burned to a degree of hardness such that it is vitreous, will not prove as satisfactory upon the roof as a medium hard one. The extremely hard tiles will sweat, owing to their inability to absorb the moisture condensed upon their under surfaces.

While the foregoing method of testing the hardness of the various commercial tiles and the vitrification trial pieces was very crude, it has shown one point quite clearly, viz., that the best commercial colors of the clays are found to correspond quite closely to the hardness of steel or a trifle below. The moment the trial piece becomes harder than steel, the fracture appears vitreous, and the color in most cases becomes too dark. These latter tile would be too hard for economy in commercial handling. In the light of the foregoing data and discussion, we may say that the hardness phenomena of the typical roofing tile clay will be about as follows:

TABLE No. 18.

Range of Hardness of Typical Roofing Tile Clay.

Cone.	Hardness Data.	Commercial Grade.
010	Generally soft and easily cut.	Too soft.
08	Generally soft and easily cut.	Too soft.
06	Difficultly cut.	Generally too soft.
04	Very difficultly cut	Generally good.
02	Steel hard	Prime.
1	Harder than steel	Getting too hard.
2	Harder than steel	Too hard.
3	Harder than steel	Too hard.
4	Harder than steel	Overfired.
5	Harder than steel	Overfired.

Hardness vs. Vitrification Range.—In order to reduce the foregoing mass of data to a more compact form, for the purpose of drawing

conclusions more easily, the following symbols were used in the following table:

Degree of Hardness	Symbol
Very easily scratched	½
Easily scratched	1
Difficultly scratched	2
Very difficultly scratched	3
Equal to steel	4
Harder than steel	5

Assembling the data in this form, we have:

TABLE No. 19.

Hardness as a Gauge of the Vitrification Range.

Cone	Clay Samples.														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
010	1	1	½	½	1	½	½	1	2	2	2	2	1	1	1
08	2	1	1	½	1	1	1	1	2	2	2	2	1	1	1
06	2	2	1	1	2	1	3	1	3	3	3	3	2	2	2
04	4	3	2	2	2	2	3	2	3	4	5	3	2	2	2
02	5	3	4	3	2	2	3	2	3	4	5	3	2	2	3
1	5	3	5	5	4	5	5	5	3	5	5	4	3	3	4
2	5	4	5	5	3	5	5	5	4	5	5	5	5	3	4
3	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5
4	5	5	5	5	5	5	5	5	4	5	5	5	5	3	5
5	5	5	5	5	5	5	5	5	4	5	5	5	5	–	5

The heavy line has been drawn in the preceding table at a point supposed to represent the transition of the clay from the stage where it can barely be cut, to the steel-hard stage. This particular hardness cannot be correlated with either the beginning of commercial grades or the end of them. It is likely to represent the middle of the valuable period of the clay's life—not too soft to stand weather, nor so hard as to be brittle and glassy.

It will be seen that clays I and N, both of which are poor materials, high in lime and of bad color, show a slow or gradual hardening, and have a different vitrification habit from the other clays. Aside from these two clays, the line clings closely to the temperature zone 04-02-1.

It is not possible to show the *range* of the vitrification process by hardness data, as well as by color or other tests, for no change of hard-

ness occurs to mark the condition of overfire, until the latter becomes excessive.

Porosity—The vitrification process in clays is most accurately marked by the changes in porosity of the sample. Vitrification means the assumption of a dense condition by a body originally always porous and sponge-like in structure. The vitrified body may or may not be vitreous, or glass-like. It may even be still notably porous, at the stage where it attains the best approach to a dense, vitreous structure that it is able to make at any temperature. Some clays never do vitrify to any satisfactory degree, but after gaining strength, hardness and density to only a moderate degree, they begin to undergo the bloating and destructive changes of overfire.

Vitrification is brought about by partial fusion of the mass, or rather the progressive fusion of portions of the mass and the attack on the still solid remainder by this fluid magma. As the fusion proceeds, the spaces between the original grains fill up and are obliterated, and if carried to the extreme of perfect fusion, the mass would become like a glass, entirely solid and devoid of recognizable pores.

Since clay wares are not fused and cast in moulds, as glass or metal is, but are moulded while plastic with water, and merely carried up to such hardening as is safe without loss of shape by fusion, it follows that the initial structure of the mass is always preserved to some extent, and the voids between the grains, which constitute from 30 to 40 per cent. of the volume of the clay at the end of the dehydration and oxidation process, are never fully closed up. Consequently, all clay wares are somewhat porous, or rather they contain cavities filled with air or gases. But the voids are inter-communicating in the beginning; the clay is *porous* in the real sense of the word, and fluids or gases will permeate it freely. But as vitrification progresses, the communication between voids becomes less and less perfect, and when the process is complete, in the sense of having reached the best combination of qualities that the clay can produce, these voids usually communicate to only a very limited degree. They are mostly present now as gas-blebs or sealed cavities, and are not properly pores at all. A clay burnt to this stage is not able to absorb much if any water, because the cavities inside do not reach the surface.

The extent to which the porosity of a given clay will be extinguished under heat treatment will be dependent upon many factors—the mineralogical composition of the clay, the size of its grains, and their proportions, and the intimacy of the mixture are prominent factors. For instance, calcium carbonate, if finely ground and evenly distributed throughout a clay mass in not too large proportion, will cause early and very rapid fusion of the body, but, should a like quantity of the same material be added in coarse, granular, or lump form, it will have but very little effect upon the mass, and combination will occur only

at the points of contact. The rate at which the heat is applied, the pressure on the mass, and the chemical condition of the fire gases, also affect the rate of vitrification profoundly.

In a study of all the changes that occur in the burning of a clay, there is no single factor that will explain what has taken place as well as a close study of the porosity changes. From these may be detected very clearly, not only the rate of the vitrification process as a whole, but also the periods of rapid or slow action, and the point where the failure of the mass begins. From what may be learned from the porosity curve, very safe conclusions can be drawn as to the suitability of a given clay for manufacture, so far as its vitrification behavior is concerned.

The percentage porosity expresses the relation between the volume of pore space and the combined volume of the particles of which the clay is composed. It is, in other words, the ratio of the void spaces to solid particles.

Dr. E. R. Buckley[1] gives the following formula for determining porosity:

$$100\,\frac{(W - D)\ \text{Sp. gr.}}{(W - D)\ \text{Sp. gr.} + D} = \text{per. cent. porosity.}$$

W = saturated weight.
D = dry weight.
Sp. gr. = The composite specific gravity of the clay particles, as calculated from the dry, saturated, and suspended weights of the trial pieces.

Purdy[2] has simplified the formula of Dr. Buckley to the expression:

$$100\,\frac{W - D}{W - S} = \text{Porosity.}$$

The Purdy formula was used in this work.

The trial pieces for this measurement of porosity were obtained by breaking the one inch by one inch by six inch vitrification trial pieces in two. These pieces were carefully dried on a hot plate to constant weight; then, without allowing time to absorb water from the atmosphere, they were weighed on a chemical balance, accurate to one-hundredth of a gram.

Each trial piece was then immersed in distilled water, with one end slightly exposed to allow easy escape of the air. At the end of 24 to 30 hours, they were placed under a bell-jar and the air kept exhausted for a period of about 4 hours, it having been found necessary to hold

[1]Wisconsin Geol. and Natural History Survey, Bull. VII, Econ. Series 4, p, 20.

[2]Purdy, R. C. Illinois Geological Survey, Bull. 9, p, 142.

them under vacuum for that length of time to bring out the last traces of gases that would come out of the interior voids.

After this treatment, the trial pieces were suspended, one at a time, by means of a silk thread, from the beam of a chemical balance and their saturated weights taken. While still suspended by the thread, a beaker partly filled with distilled water was brought up from below, so that the briquette was immersed in water and could still swing clear from the sides of the beaker. Thus the suspended weight of each trial piece was taken.

These three determinations, applied in the formula before quoted, gave the porosity in per cents. These figures were obtained on each trial piece, representing each temperature at which draws were made, from the standard list of roofing tile clays.

TABLE No. 20.

Showing Porosity of the Standard Roofing Tile Clays, Fired to Different Stages of Vitrification.

Designation of Clay.	Heat Treatment Expressed in Cones.									
	010	08	06	04	02	1	2	3	4	5
A	29.53	25.77	18.11	11.52	7.48	4.95	3.00	2.51	1.08	1.23
B	31.07	31.12	26.80	25.76	26.15	21.92	19.29	12.57	14.04	3.12
C	35.94	35.02	32.45	17.00	14.30	7.41	5.22	4.07	1,10	0.98
D	32.85	32.08	33.39	24.59	13.04	12.62	10.12	2.62	0.74	0.80
E	38.42	39.87	39.34	41.67	40.10	12.50	26.46	1.90	2.72	1.33
F	33.99	31.83	33.48	23.65	24.61	12.08	16.83	2.93	0.60	1.24
G	28.31	27.73	19.03	16.19	16.69	8.22	9.10	8.77	8.42	7.82
H	30.96	24.88	29.94	24.95	25.37	8.05	16.20	1.65	2.56	1.97
I	33.04	33.33	32.10	32.17	32.10	29.62	23.88	17.94	15.32	0.52
J	24.55	22.98	11.22	9.30	9.15	7.41	7.17	7.40	7.88	9.21
K	17.53	14.48	8.24	5.77	1.71	0.65	0.80	Bloa	ted	....
L	27.26	24.82	22.59	18.35	15.50	15.63	12.76	10.55	5.20	4.45
M	29.88	29.42	28.49	28.73	27.74	21.43	10.73	3.66	3.10	0.51
N	37.12	38.25	37.64	37.20	36.42	18.25	17.86	5.68	21.04	1.01
O	27.31	32.23	29.04	22.85	20.04	8.84	11.74	7.31	3.92	5.35

Analysis of the Porosity Data.—In order to facilitate the reading and meaning of the data in the preceding table, an effort has been made to classify the clays shown into three different groups and to depict by curves the percentage porosity of the clays of each group.

Group I. This group is of exceedingly narrow vitrification range. It comprises clays E, N, M and H. In none of this group do any serious or significant porosity changes occur prior to cone 02, but immediately following that point the porosity drops very rapidly until, at cone 3, vitrification is practically complete and no further diminution of porosity occurs with further accessions of heat (Figure 26). This signifies that the vitrification process or the mutual solution of the minerals

of the clay does not begin early, but that it proceeds with great vigor when once begun. They indicate also that if the burning process is interrupted at a point between cones 02 and 3, that the tiles in the kiln would be apt to show a very irregular degree of porosity, for in no

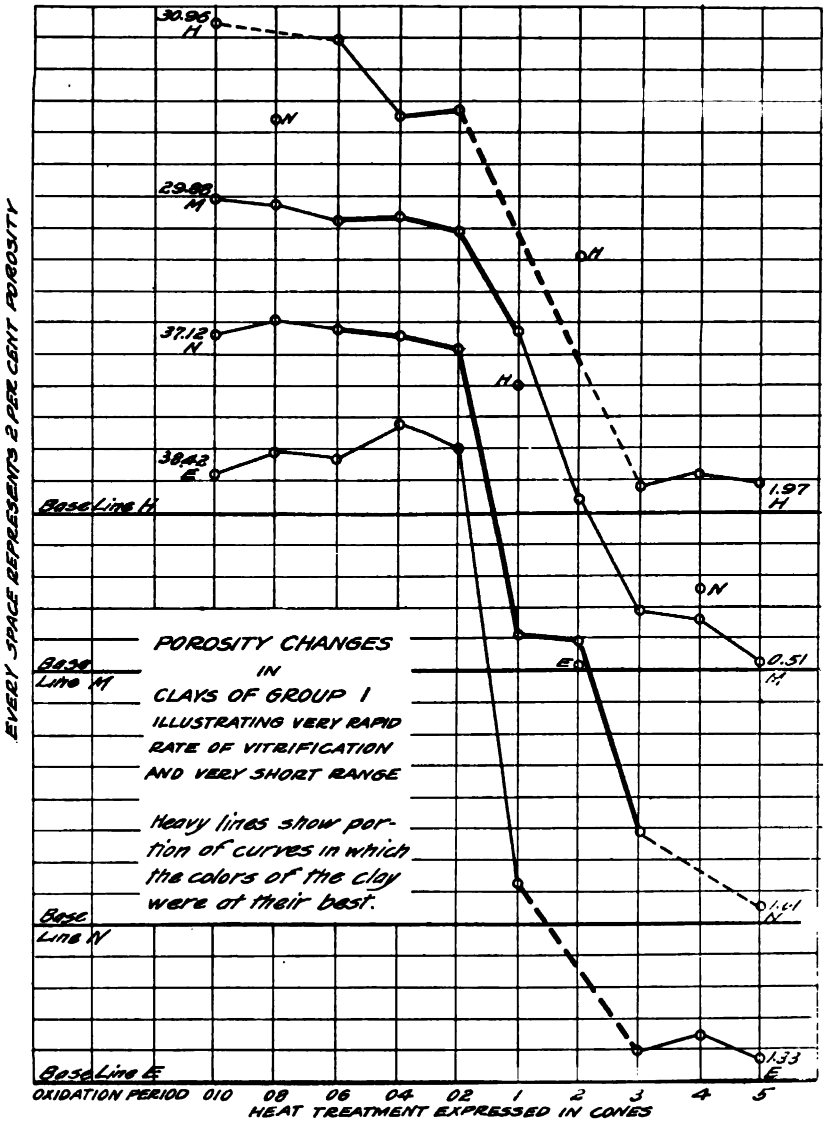


Fig. 26—Porosity Changes in Clays of Group I.

ordinary kiln-burning of such wares is the entire kiln likely to fall within a range of one cone in temperature. But in the four clays cited, one cone in temperature stands for a large reduction in porosity, so that with ordinary variations of kiln temperature we should have great variations in vitrification.

In the following table are shown the facts as to the porosity changes per cone for clays composing this group:

TABLE No. 21.

Porosity Changes per Cone in Group I.

Designation of Clay.	Temperature Range.	Number of Cone Intervals.	Reduction in Porosity Per cents.	Reduction in Porosity Per Cone.
E	02-3	4	38.20	9.55
N	02-3	4	30.74	7.68
M	02-3	4	24.08	6.02
H	02-3	4	23.72	5.93

The facts shown in this table constitute a serious indictment against these clays, of course. If the ware were of a sort that permitted selling in a wide variety of hardness, as common bricks do, so that the kilns need not be raised above cone 02, or if the ware could be kept in shape well at temperatures exceeding cone 3, so that all of the kiln could be brought to that point, constant physical structure in the product, so far as porosity is concerned, would be expected.

The color-temperature range has been indicated on these curves for the purpose of showing in what portion of the burn the colors are most satisfactory. We find considerable variations, but in three of these four clays, the colors are as good as the clays respectively can generate for a period preceding active vitrification. If the kilns could be finished off at these temperatures, then the burning would be relatively easy. But, the porosity being still almost unaffected, the wares would be altogether too soft for use. Later, when the clay has shrunk and become dense and hard, the color is no longer suitable for roofing tiles. In the case of clays N and E, both are calcareous, buff-burning materials and would require slipping at any temperature to get a marketable color.

It should be noted that three erratic determinations have been rejected in drawing these curves. The determinations are plotted, with the clay that they belong to marked beside them, but they seem so certain to be due to some discrepancy in weighing, or recording, or to uneven heat distribution in the test kiln, that they have not been considered in the above remarks or the curves.

Group II.—This group comprises clays of moderate vitrification range and rate. It includes clays A, C, D, F and O. There are several determinations here also that seem unduly erratic, especially clay F at cones 02 and 2, and clay O at cones 010 and 1. They have been plotted, but the curves have been drawn with allowances or corrections in accordance with the preponderance of the data. (See Figure 27.)

These clays differ from the first group in three respects. First, they do not delay so long in beginning to undergo important porosity changes. At cone 08, in all but clay O, and at cone 06 in the latter, the vitrification process is evidently busy at work. Second, they do not progress at nearly so rapid a rate, as they are not down to minimum porosity till cone 4 is reached. This shows a complete vitrification range of eleven cones, or approximately 220° C., as against four cones for group one.

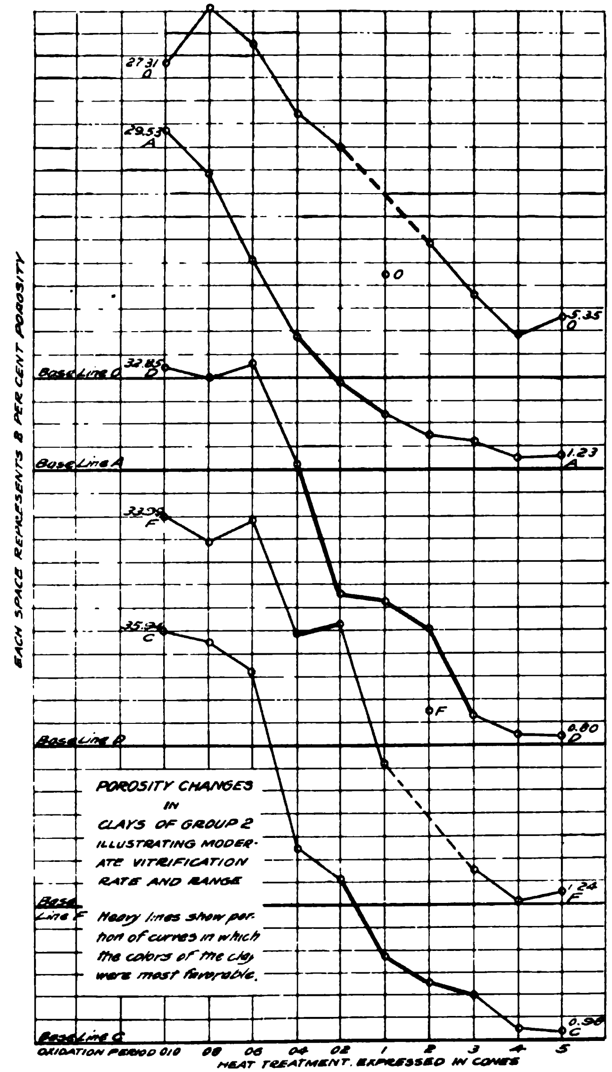


Fig. 27.—Porosity Changes in Clays of Group II.

The average reduction of porosity per cent. per cone in this group, between cones 08 and 4, is about 2.70%. In the following table are shown

the facts as to the clays composing this group, in the zone of their most rapid vitrification:

TABLE No. 22.

Porosity Changes per Cone in Group II.

Designation of Clay.	Temperature Range.	Number of Cone Intervals.	Reduction of of Porosity Per cents.	Reduction of of Porosity Per Cone.
C	06–1	6	25.04	4.17
F	06–1	6	21.40	3.56
D	06–1	6	20.77	3.46
A	08–02	6	18.29	3.05
O	06–1	6	20.20	3.36

The reduction in porosity, in the most rapid part of the process, over a range of 6 cones is much lower than in 4 cones in Group No. 1. If the entire vitrification range of these clays (instead of the most rapid part only) were included, it would show a still more striking contrast.

Third, the period of good color occurs after vitrification is relatively well advanced—much later than clays H and M in Group No. 1. There is a chance, therefore, to get these clays finished off during a period of relatively slow vitrification change, which is essential to safe and profitable burning.

Group III.—These are clays of slow vitrification rate and wide range. This group comprises clays B, G and L. Clays I, J and K, which are blended to produce L, are not given a separate position, because none of them are by themselves used for roofing tile manufacture.

The clays of Group No. 3 show three erratic determinations, two in clay L, at cone 02 and 1, and one in clay B at cone 4. These determinations have been plotted, but not drawn into the curves. They are probably due to experimental errors, very likely in irregular heat distribution in the test kiln. (See Figure 28.)

This group is characterized by a continuous and gradual reduction of porosity from cone 010, when the first draw-trials were taken, to cone 5, when the last was taken, and none of them were yet as dense as many clays become. Their average drop in per cent. absorption per cone, over the range in which vitrification is in progress, is about 1.7% over the whole zone. Clay B belongs to this group with less certainty than the others. It might be graded in Group No. 1 nearly as well.

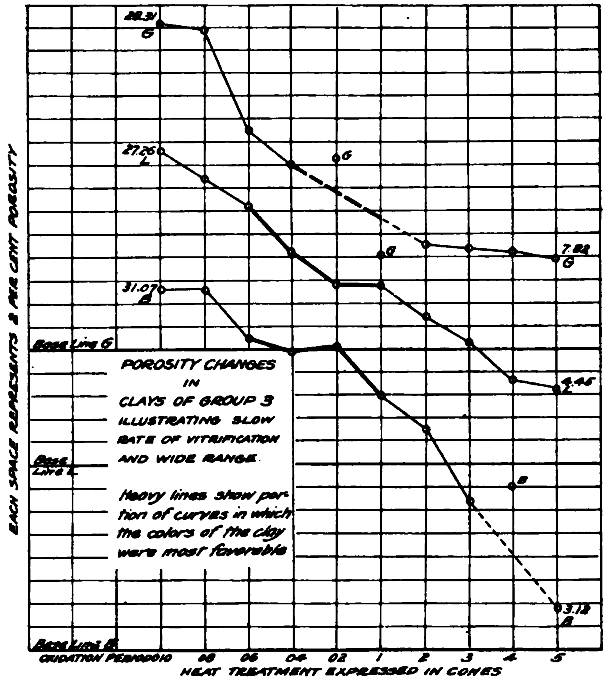


Fig. 28—Porosity Changes in Clays of Group III.

In table No. 23, the porosity changes per cone are contrasted·

TABLE No. 23.

Porosity Changes per Cone in Group III.

Designation of Clay.	Temperature Range.	Number of Cones Interval.	Reduction in Porosity Per cents.	Reduction in Porosity Per Cone.
B	04–1	6	13.58	2.26
G	08–02	6	11.54	1.92
L	010–04	6	8.91	1.48

The zone of commercial color is seen to occur in the middle of the vitrification process, but with changes progressing so slowly that it should be possible to fire a kiln off with fairly uniform color throughout.

The clays of this group have an undoubted advantage over both preceding groups, so far as the evidence of the porosity changes is concerned. If satisfactory in other respects, they should be very safe in the kiln.

For purposes of comparison, the following curve-sheet (Figure 29) containing clays I, J, K and the body blended from them, L, has been prepared. It is to be observed that clay K, which is the basis of the mixture,

has a very steady vitrification process, coming to completion at cone 02, and bloating badly if overfired beyond cone 2. This clay has evidently begun to vitrify well before cone 010, as the porosity at cone 010 is only 17.53%, which is too low for any clay in its period of maximum openness of structure.

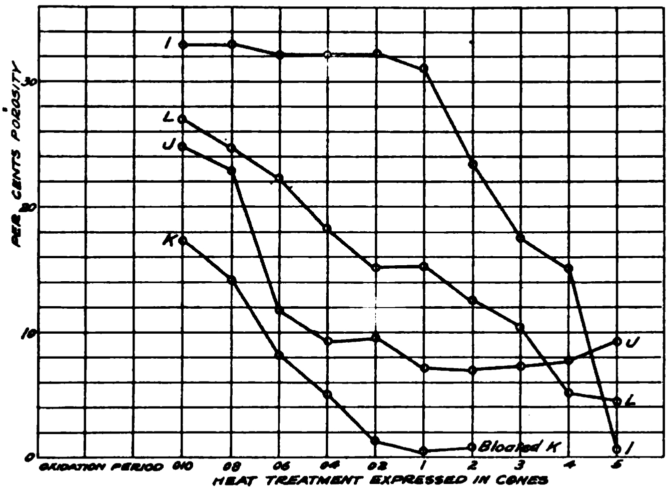


Fig. 29—Porosity Changes per Cone in Clays I, J, K and L.

To this regular but very early vitrifying clay are added I, a clay clearly belonging to Group No. 1, which vitrifies hardly at all until cone 1, and clay J, which vitrifies rapidly at cone 06, and thereafter changes little in the temperature limits tested, but which reaches only a very imperfect vitrification at best.

L, the mixture or composite clay, shows beautifully the influence of these components. Its course is parallel to clay K, but its progress is much delayed, so that when clay K is fully vitrified and ready to swell from overfire, clay L has still 12.75% porosity, and this is not wholly eliminated by going to cone 5, though the body becomes undesirable for roofing tile long before that point.

In view of the fact that clay K has a good color by itself and apparently a good, though very early vitrification behavior, it would appear that the addition of clays I and J to it, spoiling not only its color but its vitrification behavior as well, is unfortunate. The occurrence of the three clays in the mine would make it difficult and expensive to mine clay K without also mining I and J, which is the reason for their inclusion in the mixture.

Summary on Porosity Changes.—The grouping of the twelve roofing tile clays into three more or less clearly defined groups on the strength of their porosity curves is not, however, a conclusive or satisfactory decision as to their quality. Good clays and bad ones, judged by other and not less important criteria, are found both in and out of each group.

Considering the clays in two groups—those of good color and those of bad—and listing the porosity data opposite each we have:

TABLE No. 24.

Comparison of Color Range and Porosity Behavior.

Designation of Clay.		Character of Porosity Curve.
A	Clays of good commercial color range.	Wide vitrification range. Slow changes. Process complete at cone 3.
B		Wide vitrification range. Slow changes. Process complete at cone 5.
C		Rather narrow range. Rapid changes between cone 06 and 04. Moderate between 02 and 3, in zone of useful colors. Complete at cone 4.
D		Rather narrow range. Rapid changes between 06 and 02. Complete at cone 3–4.
G		Wide range. Changes slow. Process incomplete at cone 5.
H		Narrow range. Sudden changes between cones 02 and 1. Changes complete at cone 3.
M		Narrow range. Sudden changes between 02 and 3. Finishes process at cone 5.
O		Fairly wide range. Changes steady and not rapid. Changes incomplete at cone 5.
E	Bad colors.	Very narrow range. Rapid changes between 02 and 3. Complete at cone 3.
F		Rather broad range. Erratic. Most rapid changes between cones 02 and 1. Finishes process at cones 3 and 4.
L		Very wide range. Slow processes, incomplete at cone 5.
N		Very narrow range. Changes very rapid between cone 02 and 3. Vitrification complete at cone 5.

Thus we have six clays whose vitrification range is good; four of these have good color, while two are of poor colors, though not the worst. On the other hand, we have six clays whose vitrification range is narrow. Of these, four have good colors, while two have colors entirely unfit for use without slipping.

In view of these facts, it can hardly be claimed that a typical roofing tile clay can be set forth, judged on the basis of its porosity changes.

Porosity vs. Vitrification Range.—While the definition of a type clay is not possible from the foregoing evidence, it is not so difficult to construct an ideal of what the porosity changes should be to constitute

a desirable clay from the standpoint of safe burning. Suppose the clay in question is to reach complete maturity of color at cone 1. The following may be taken as a desirable porosity behavior.

TABLE No. 25.

Relation Between Porosity Behavior and Color, in Ideal Roofing Tile Clay.

Temperature Expressed in Cones.	Porosity Expressed in Per cents.	Color-Sequence and Structure.
Below 010	.. to 30	Light yellow or pinkish reds—not commercial. Structure very porous.
010	30 to 26	
08	26 to 18	
06	18 to 10	Commercial red colors, ranging from light to dark. Structure, sufficiently dense.
04	10 to 6	
02	6 to 4.5	
1	4.5 to 3	
2	3 to 2	Colors too dark. Body at greatest density.
3	2 to 3	
4	3 to 4	Colors entirely overdone. Body beginning to swell from overfire.
5	4 to 6	

Whether any given clay reaches its maturity at the temperature limits indicated above, is not so important as that the general shape of the porosity curve should be substantially as shown. Its most rapid changes should occur before the development of the best commercial colors; then a period of good colors and relatively small porosity changes, merging into a zone of darker colors, and still less body change, and finally destruction of marketable colors and the increase of porosity from the swelling of the body.

Specific Gravity—Until recently the specific gravity, while frequently determined, has yielded little if any intelligent insight into the clay's qualities. It was found that *per se* the specific gravity of a clay did not clearly indicate anything, pro or con. It remained for Purdy[1] to make the first effective use of this determination, which he did by determining the specific gravity of clays at a series of stages of burning, and also by adopting precautions to get the real, as well as the apparent specific gravity. In his hands, this determination has been useful in analyzing the processes taking place in the vitrification of clays, and he has reinforced the evidence obtained from the porosity and shrinkage studies. It has been of special importance in bringing out and demonstrating the amount and volume of the sealed pores in vitrified clay bodies, the existence of which could not be proved by absorption or porosity measurements.

[1]R. C. Purdy, Illinois Geol. Survey, Bull. IX, p. 133.

Method of Determination.—The formula by which the apparent specific gravity of a lump of any substance is obtained is $\frac{D}{D-S}$ in which D = the dry weight of the substance and S = the weight of the same substance suspended in water.

The true specific gravity is determined from the powdered material, ground so fine as to make the existence of any sealed pores or gas cavities in the grains a matter of some improbability. This determination is made in a small flask, accurately standardized, and called a pycnometer.

In the work done in this report, no effort was made to pursue these investigations to the refinement that has been shown in the work of Purdy[1], which should be consulted for further details on the capabilities of this mode of research. The determinations were made by the simplest process and represent the apparent specific gravity only.

The same test pieces used in the porosity test were used, and the same weights. The porosity data being at hand, a mere calculation suffices to obtain the apparent specific gravity and for this reason it has been deduced and tabulated. (See page 123.)

Examining the data of the foregoing table, it may be observed that in every instance the changes in value run along with small variations from low to higher temperatures, until finally a sudden or marked drop occurs. The point where the drop occurs is as early as cone 04 in the case of clay K, while it only occurs at cone 5 in five other samples.

The significance of this break in the figures of each clay is as follows: While the clay remains porous or only partially vitrified, its voids are very largely permeable by water, especially if resort be had to boiling or the vacuum pump to suck out the air and allow the liquid to take its place. Hence calculation, as per the formula above, gives a close approximation to the true specific gravity. But, when the fusion progresses to the point of sealing up the voids, or creating new blebs, from the evolution of gases inside the sticky, glassy matrix, then a determination of the specific gravity of the lump gives results too low, for the gases are only very imperfectly replaced by water, and the denominator of the fraction $\frac{D}{D-S}$ becomes too large, owing to the increased displacement of the swollen lump, without proportionately increased weight. If the mass continued permeable to water, then the value of D — S would remain constant, whatever its volume.

The reduction of the apparent specific gravity of the trial pieces indicates, therefore, the growth of sealed blebs or cavities, and this in turn indicates progress towards a pasty, sticky stage of vitrification or semi-fusion. A clay is therefore certainly deteriorating in structure when its apparent specific gravity grows markedly less.

[1]Loc. cit.

TABLE No. 26.

Showing Changes in Specific Gravity of the Standard Roofing Tile Clays at Different Stages of Burning.

Designation of Clay.	Temperature Expressed in Cones.									
	010	08	06	04	02	1	2	3	4	5
A	2.54	2.52	2.45	2.52	2.48	2.46	2.42	2.41	2.25	2.23
B	2.66	2.67	2.68	2.68	2.68	2.70	2.61	2.57	2.56	2.35
C	2.63	2.66	2.64	2.56	2.55	2.50	2.49	2.45	2.30	2.26
D	2.54	2.58	2.63	2.58	2.60	2.50	2.47	2.40	2.28	2.20
E	2.63	2.75	2.73	2.76	2.62	2.51	2.60	2.39	2.05	1.60
F	2.58	2.56	2.63	2.56	2.56	2.71	2.53	2.34	2.06	2.04
G	2.68	2.69	2.68	2.67	2.57	2.62	2.53	2.54	2.51	2.35
H	2.60	2.58	2.55	2.58	2.52	2.42	2.50	2.32	1.93	1.73
I	2.67	2.67	2.64	2.64	2.63	2.55	2.55	2.45	2.44	1.93
J	2.56	2.55	2.50	2.50	2.49	2.43	2.39	2.39	2.39	1.96
K	2.46	2.46	2.44	2.44	2.34	1.88	2.00	.....	.....	.....
L	2.61	2.54	2.62	2.59	2.63	2.51	2.35	2.27	1.15	1.20
M	2.56	2.57	2.67	2.66	2.62	2.62	2.50	2.44	2.41	2.21
N	2.64	2.70	2.68	2.67	2.66	2.43	2.44	2.36	2.46	2.02
O	2.50	2.53	2.52	2.50	2.48	2.45	2.45	2.44	2.42	2.13

Judged by this standard, the clays pass the line from a reasonably sound structure into a rapidly failing stage at the point indicated in the table by a heavy black line in each horizontal column.

Comparing these determinations of the failing point of the clay with those obtained from the porosity test, we find that the specific gravity indicates a clay as failing earlier than by the latter, often several cones earlier and usually at least one. There are, however, wide variations in the extent of the indicated failure, and these are much more easily recognized by means of curves.

For convenience, the clays are drawn on curve sheets (Figure 30) in the order of their reduction in specific gravity, from the maximum to the minimum of each clay. Thus clay A changes only 0.31 between its maximum and minimum, showing that at cone 5 viscous swelling, or

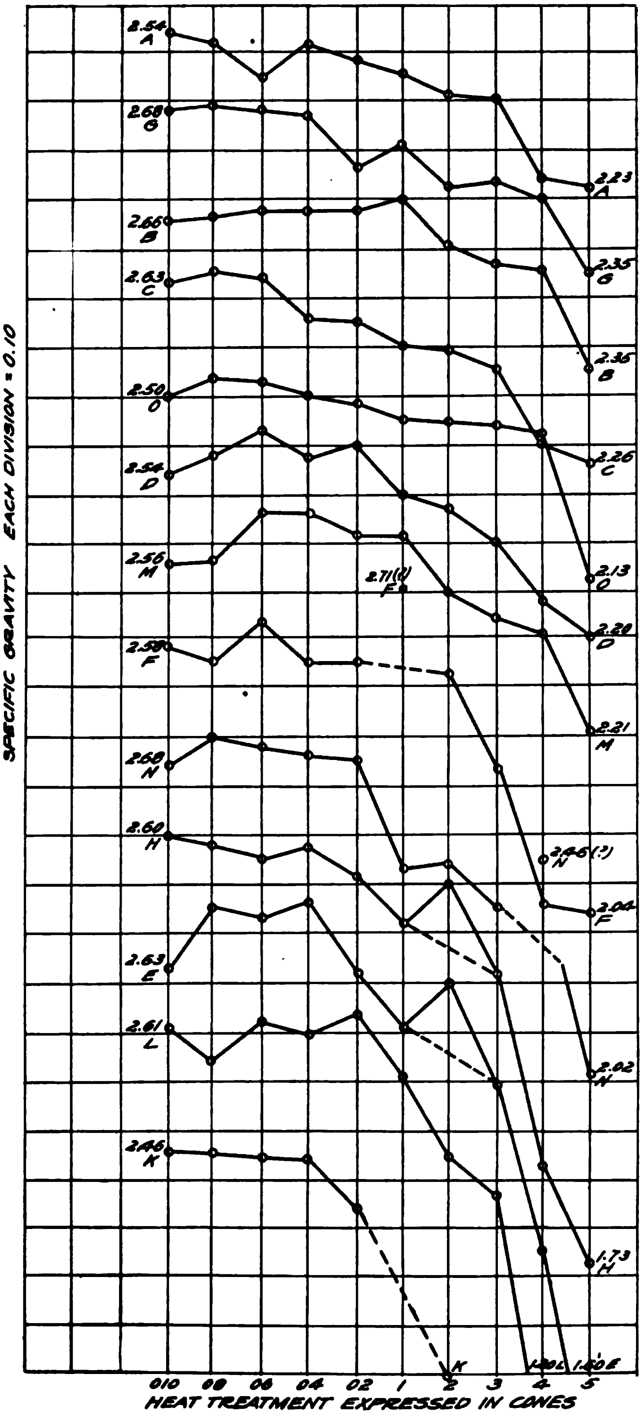


Fig. 30—Curves Showing Changes in Specific Gravity of the Standard Roofing Tile Clays at Various Stages of Heat Treatment.

development of sealed gas blebs, had progressed to a small extent only. Clay L, on the other hand, changed 1.48 in specific gravity in the same heat treatment, showing the clay was far gone in viscous bloating. No effort has been made to group these clays according to the actual numerical value of their specific g avity, as this is a function of their mineral composition. It will be noted that the bad, limy clays E and N both show exceptionally high specific gravity, 2.76 and 2.70 respectively.

A study of these curves shows a very considerable variety in their details, but the tendency is for each clay to attain a maximum, somewhere prior to cone 02, and thereafter fall away more or less sharply, as the sealed pores begin to affect the volume.

Clays A, G, B, C, O, D and M all have curves in which the reduction is moderate in amount, and occurs late enough in the firing, to show that these clays have wide vitrification ranges and safe vitrification habit. Clays F, N, H, E, L and K all show curves in which the reduction is large in amount and rapid in rate, and indicate clays of unsafe vitrification habit.

It will be noted that the clays which are condemned in the color test, E, F, L and N, are all condemned by this specific gravity test also, and with them clay H, whose color is good.

No standard of specific gravity for roofing tile clays, either in numerical amount or in rate of change, can be set as the result of this inquiry, but in comparison of other clays with these, a similarity of general contour with the clays here known to be of good working quality, would tend to confirm other sources of judgment.

Total Shrinkage—The total shrinkage is a property of much concern to the roofing tile manufacturer. Of the total shrinkage which occurs between the moulding of the plastic clay and its recovery from the kiln, that part of the change in volume which occurs in burning is of more vital importance. Proper pallets and forms can be made to hold a piece of clay straight and true while drying, but such devices, while possible in the burning, are too costly for wares which sell as cheap as roofing tiles. In an earlier part of this chapter, the drying shrinkage has been discussed in detail, and there now remains to consider the shrinkage in burning.

A knowledge of the total shrinkage of a clay has a direct practical application, as it furnishes the information necessary to construct dies and moulds of the proper size to make a piece of ware that will, when burned, have the proper size and dimensions.

In order to obtain the correct total shrinkage for practical purposes it is, of course, necessary to grind the clay to the proper fineness, temper with the right amount of water and burn to the temperature required in the actual manufacture of the ware.

The cause of the shrinkage of the clay is the same as the force which extinguishes the porosity and converts a spongy, cellular mass, full of voids, into a dense resistant solid that steel will not cut nor weather crumble. The vitrification or interaction of the minerals, and their mutual solvent effect on each other at high temperatures, causes the particles composing the old mass to disappear and the spaces between to close up. This produces a shrinkage, which is usually greater in proportion as this action is more complete.

But there is another force which tends to counteract this shrinking tendency, which has been discussed in connection with porosity and specific gravity studies. This is the tendency to form gas blebs or bubbles in the mass, which, unable to escape, swell as the temperature increases and tend to convert the clay into a cindery or frothy slag. These two processes are working against each other during vitrification. The shrinkage is more powerful for a time, and the clay grows less in volume in spite of the thousands of minute gas cavities that are forming. But after a time, the swelling action is the more powerful, and then the shrunken clay begins to bloat, and may assume its initial size or even become much larger than it ever was.

The causes of this swelling and the conditions and mineral com position which especially favor its development will not be discussed at greater length at this time. It is merely necessary to point out that if the shrinkages of a series of test pieces fired to progressively higher temperatures be measured and plotted on a curve, we will find that in nearly every clay the curve rises with the temperature for a time, sometimes at a uniform gradual rate, and sometimes very suddenly, and then after reaching a maximum, it usually stands more or less constant in volume for a time, the shrinkage and bloating reactions being in a deadlock so to speak, and then the bloating triumphs and the volume increases again.

The determination of the shrinkage in the test of the standard series of roofing tile clays was on the same series of test pieces which had been measured for the determination of the drying shrinkage. The methods of firing, drawing, cooling, etc., were as described in connection with the preceding tests for color, hardness, etc. The results are shown in tablê No. 27, page 127.

In order to get the assistance of the graphic method, the data of the above table were plotted in a series of curves, excluding that from clays I, J and K, which are represented in their blend or mixture, clay L, but which have no separate use for roofing tiles (Figure 31). In plotting the above curves,efforts to divide up the clays into groups of similar behavior were not satisfactory or illuminating. Each clay has therefore been plotted singly, though arranged in the order of decreasing total shrinkage value, viz., clay O with 14.00 per cent. is first, clay C with 13.60 per cent. is second, etc., The beginning and ending of each curve is

TABLE No. 27.

Showing Total Linear Shrinkage of Standard Series of Roofing Tile Clays.

Designation of Clay.	Heat Treatment Expressed in Cones.									
	010	08	06	04	02	1	2	3	4	5
A	4.90	6.00	6.60	9.90	10.90	11.80	12.20	11.60	11.90	11.00
B	3.00	3.25	5.00	5.00	5.00	5.75	7.00	7.00	8.00	7.50
C	4.60	6.30	6.70	10.50	11.90	13.50	13.50	13.20	13.60	13.30
D	3.10	3.30	2.90	7.00	7.30	11.20	11.60	13.00	13.20	12.60
E	6.00	4.60	4.90	6.20	5.60	10.30	9.50	13.00	10.00	*6.00
F	4.60	5.30	5.30	8.60	8.00	11.80	10.30	11.00	11.90	11.00
G	3.00	4.00	6.50	6.25	7.25	7.50	8.50	8.00	7.00	*5.50
H	7.20	7.60	7.60	9.70	8.30	12.50	11.30	13.00	*	*
I	5.00	5.00	5.00	5.00	4.50	5.50	6.75	8.00	*7.50	6.00
J	7.25	8.00	11.50	11.50	12.00	12.00	12.00	12.25	12.25	*7.75
K	7.40	8.80	11.40	12.70	13.82	8.23	*	*	*	*
L	7.70	7.70	8.50	10.30	10.30	10.30	9.70	*8.80	0.50	2.00
M	3.00	3.50	5.00	5.25	5.25	7.00	7.00	10.00	10.00	*8.75
N	5.50	5.50	6.50	6.00	6.50	9.00	9.50	11.00	10.00	*
O	4.00	4.00	5.00	5.75	9.50	12.50	12.50	14.00	13.00	*10.60

*Overfired.

marked with the proper percentage, from which the imaginary base-line for each curve can easily be picked out. No two curves refer to the same base-line.

By this method of plotting, the shape or contour of a number of curves can be easily and rapidly compared, and the numerical value of each can be ascertained with a moment's attention.

Inasmuch as these clays have already been studied for color changes, and the temperature zones within which they are of commercial grade have been determined, it was thought useful to plot these zones on the shrinkage curve of each clay. Thus clay O is of commercial color between cones 02 and 3, and the line is doubled in thickness between these points, to indicate that this zone only is of direct use in the roofing tile industry.

Lastly, the angularity and inconsistent jogs of the curves are not to be construed literally at all. Clays probably do not shrink in this erratic fashion. Shrinkage is not a free factor—the structure of the clay mass, its shape, size, its position in the kiln, its cooling treatment and many little things all unite to make shrinkage data erratic, and only by obtaining large numbers of tests on one clay, and averaging them, could the true course of the shrinkage habit be accurately plotted.

Taking up the discussion of the clays, each in turn—

Clay O—This clay changes volume slowly up to cone 04, thence rapidly up to 14.00 per cent. at cone 3, bloating 4 per cent. in the next two cones. The commercial area falls in the zone of rapid shrinkage

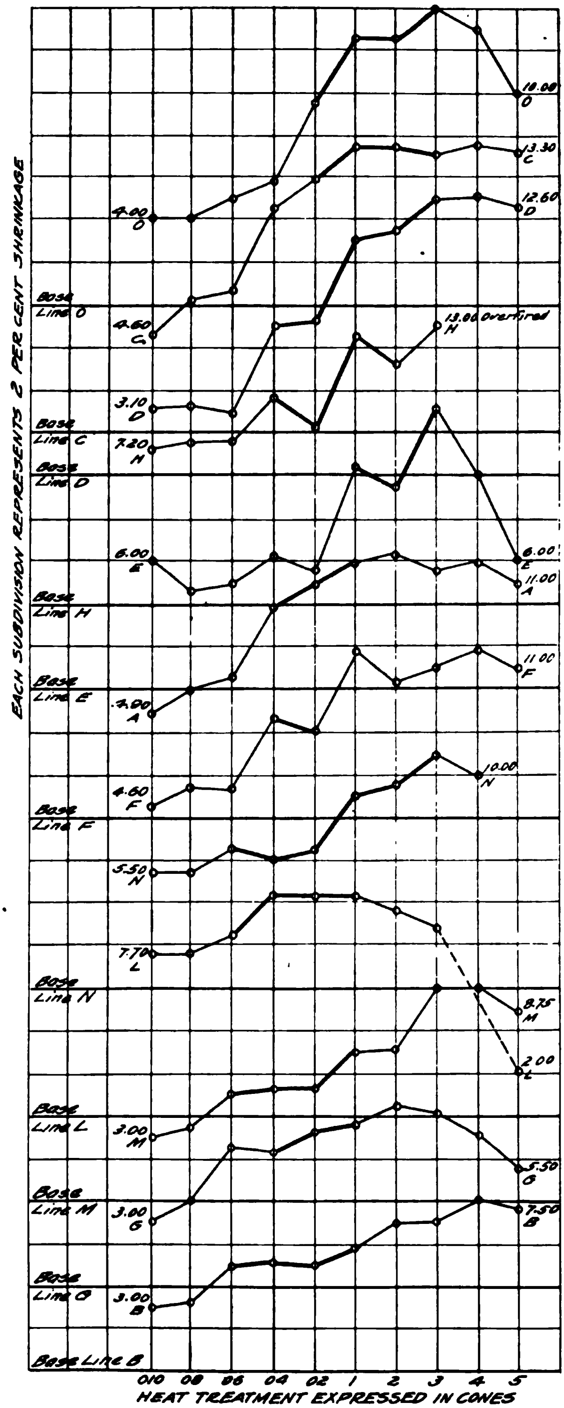


Fig. 31—Curves Showing Changes in Linear Shrinkage of the Standard Roofing Tile Clays at Various Stages of Heat Treatment.

and is immediately followed by bloating. It would seem to be difficult to so fire a kiln of this clay, as to secure even shrinkage and even color in all parts of the kiln and at the same time avoid the production of some overfired goods.

Clay C—This clay has a very much better habit. It shrinks rapidly and steadily from cone 010 to cone 02, but from cone 02 to cone 5 its volume is nearly constant. The total amount of shrinkage is high, 13.6 per cent., but this disadvantage is much more than offset by the long period of stability when shrinkage is once complete. The zone of commercial color also falls in the zone of stable volume. This clay should be of excellent properties for this purpose.

Clay D—This clay begins its volume change at cone 06, and becomes stable at cone 3, remaining so to cone 5, at least. The total amount of shrinkage, 13.20 per cent., is high. The zone of commercial colors falls in the period of rapid volume change and the difficulty of getting uniform size and uniform color would probably be considerable.

Clay H—The clay changes but little in volume till cone 04, when a moderate fire shrinkage of 5 per cent. (13 per cent. total) occurs. The clay bloats badly if fired above cone 3. The color zone from 04 to 2 coincides with the zone of most rapid shrinkage. This clay does not seem particularly fortunate in its combination of properties.

Clay E—This is a calcareous clay of buff color, requiring a slip clay covering to make it saleable. The clay does not change perceptibly in volume up till cone 02, but remains during this time very soft and not very durable to weather or wear. It can, however, be kept of constant volume over a whole kiln, and by slipping, of a constant color. It is possible, therefore, to use this material for roofing tiles with good results if the porous tiles can be disposed of. If, on the other hand, it is desired to vitrify the clay, the task is troublesome. There is no range at all at the top of the curve. Bloating and failure occur very quickly after cone 3 is reached, and prior to cone 3 the body is shrinking very rapidly. It would be impossible to produce hard, dense products from this clay in quantity, on account of the losses from either under- or over-firing.

Clay A—This clay is an unusually favorable one. The total shrinkage is 12 per cent., but its temperature range, after shrinkage is practically over, is 8 cones wide. The zone of good colors is 4 cones wide, and volume changes are largely over before the color is matured.

Clay F—The determinations are somewhat erratic, but the clay probably begins to shrink at cone 06, reaches maturity at about cone 1, remaining practically constant up to cone 5. This clay has a bad color and would have to be slipped, so that so far as can be seen a burning temperature of 01 to 3 would find the clay changing but little, and the color as good here as at any other period. Any place between cones 06 and 1 finds the vitrification process actively in progress.

Clay N—The contour of this curve seems exceptionally favorable, but the clay is one of the highly limy ones, and its slow and moderate changes are due to this fact. The body is soft and porous during the entire period, from cone 010 to cone 3, when it passes abruptly into vitrification and fusion. This clay would have to be slipped in any case, so that it could be used at the zone 06 to 01 with good results, if a porous body could be marketed.

Clay L—This clay has a drying shrinkage, but the fire shrinkage is very light and the rate of change very gentle up to cone 1. The preponderance of clay K in the mixture, with its very low point of maturity, causes the mixture as a whole to deteriorate rapidly at cone 1. From cones 04 to 2 the conditions are favorable. The clay would probably have to be slipped in any case, so that the best part of the curve should be selected as the finishing zone.

Clay M—This is a clay of exceptional properties. A good color, a very low shrinkage, a very gentle rate of change from 06 to 2, and no rapid failure from overburning imminent, make this one of the best yet considered.

Clay G—The same conditions here prevail. The clay ranges from 06 to cone 3 with gentle changes, and has a fairly wide color zone in the most stable part of the curve.

Clay B—Exceptionally favorable. Small shrinkage, slow changes, wide range in which the color is good, 06 to 1, and no rapid failure after the colors become too dark for roofing tile, make this clay an unusually favorable one for safe burning.

A summary of the above shows:

Classed as favorable—B, G, M, A, C among the red burning clays, and E, L and N among the porous, buff burning clays which would require slipping.

Classed as unfavorable—O, D, H, and F.

Fire Shrinkage.—By subtraction of the initial or drying shrinkage from the total shrinkage, we can learn the amount of change in size which is directly due to vitrification changes. This information is in some connections useful, but ordinarily the total shrinkage suffices. In the following table, (Number 28), the fire shrinkages have been calculated for the present series of trial pieces.

In examination of the fire shrinkage apart from the total shrinkage, it is undoubtedly easier to compare and contrast the vitrification changes, than when each observation is modified by the inclusion of the drying shrinkage. But it is not, in the present instance at least, possible to reach any new or different conclusions as to the relative safety or desirability of the clays, than those obtained from the study of the totals.

TABLE No. 28.

Showing Per Cents. of Fire Shrinkage on the Standard Roofing Tile Clays.

Designation of Clay.	Heat Treatment Expressed in Cones.									
	010	08	06	04	02	1	2	3	4	5
A	0.60[1]	0.50[1]	1.60	5.15	5.90	6.30	6.70	6.11	6.40	6.00
B	0.00	0.25	1.50	2.00	2.00	2.50	4.00	4.00	5.00	5.00
C	0.10	0.80	1.70	6.00	5.90	8.50	9.00	8.70	9.10	8.80
D	0.40[1]	0.30	0.10[1]	3.50	4.30	6.95	7.35	8.75	9.45	8.70
E	0.00	0.40[1]	0.10[1]	0.20	0.10	4.30	3.50	6.25	5.00	6.00
F	0.90[1]	0.20[1]	0.30	3.35	2.75	6.30	5.30	7.00	6.40	6.50
G	0.50	1.50	4.25	4.50	5.25	5.25	6.50	6.00	5.00	4.50
H	0.30[1]	0.10	0.10	1.70	0.80	5.00	3.80	5.50	[2]	[2]
I	0.50	0.50	0.50	0.50	0.00	1.25	2.75	3.75	3.75	2.25
J	1.25	1 75	4.25	5.50	5.50	6.00	5.50	5.85	5.85	0.50
K	2.59	3.89	6.49	7.79	8.69	3.10[3]	[3]	....	....	....
L	1.00	2.20	3.00	4.30	4.80	4.80	4.40	3.50	5.00[1]	3.00[1]
M	0.30[1]	0.20[1]	1.30	1.55	1.55	3.30	3.30	6.00	5.50	5.15
N	0.00	0.00	0.00	0.50	0.50	2.50	3.75	5.50	6.00	[2]
O	0.00	0.00	1.00	1.87	5.50	6.50	7.00	8.00	8.00	4.50

[1]—Increase over original dry measure.
[2]—Melted.
[3]—Bloated.

WARPAGE.

The tendency exhibited by clay wares to warp or deform at some stage in their treatment between the time they leave the machine, or die, or mould, or hands which formed them, and the time when they come from the kiln a finished product, is well known to all clay workers. It is a defect peculiar to clay products in greater degree than almost any other kind of product. Glass wares, metal wares, cement wares etc., deform but little—if they are once formed true, they will remain true unless by the intervention of some accidental, exterior force. In these products, the finishing of the form is the last stage of the process—the iron or the glass or the cement fills its mould, hardens there, and generally remains true.

In clay wares, the forming is followed by two operations upon which the permanence of the ware depends—drying and burning. In both, the clay changes its volume materially, and in the latter, it changes its chemical condition from a mixture of uncombined and unrelated mineral particles, to a more or less uniform, homogeneous solution, surrounding such portion of the original grains as still wholly or partly retain their mineral identity.

Obviously, in these profound changes, every opportunity is offered to the clay to relieve itself of any strains which may remain from the process of forming or passage through moulds and dies under pressure.

Also, strains arising from improper balance of the parts of a piece of ware, thick portions vs. thin ones, etc., result in strains both in drying and vitrification, and if the clay approaches a viscous state in firing, these strains naturally tend to relieve themselves.

Lastly, clay wares of many sorts are brought in firing as near to the condition of a viscous fluid as the stability of the shape will in any wise permit, and often a little more than is safe. Clay wares in position in the kiln are usually set so that they carry more or less weight—frequently very heavy loads—and, under the influence of the incipient viscosity, they are deformed at temperatures where a single piece, sitting free, would remain true and sound. If a clay ware reaches a degree of viscosity when it is no longer able to hold up the load of its own weight, sitting free, without deformation, it is usually considered as fused, or in a state of viscous fusion. But in this case, all changes which take place must be such as a fluid would undergo in attempting to assume the horizontal—like a sagging or "wilting" of a stand of sewer pipes, etc.

Warpage is to be distinguished from fusion only as a matter of degree. It must proceed from the viscosity of the clay mass. But it may occur in bodies which have not nearly approached the condition of viscous fusion. Further, the change of shape may be the reverse of gravitational, and the ware may spring in any direction, up or down, out or in, under the influence of strains existing in it since forming. Third, these changes may take place with but little obvious progress of vitrification. Yet in the main, and on the whole, it must be believed that it is the *viscous condition of the clay, or some portion of it,* brought about by incipient fusion in burning, *which makes warpage possible.*

Roofing tiles are peculiarly susceptible to warpage. They are thin, of large area, and often stand up from the supporting surface in the form of arches. They are cheap and must be fired *en masse*—they cannot be accorded individual heat treatment in setting, for their price does not warrant it. Hence, every opportunity of structure and treatment is present in their manufacture and it is not strange that warping is a common and almost ubiquitous defect.

The measurement or systematic study of warpage has been neglected in previous reports on the clay industry. In a search of available ceramic literature, very little could be found that touched directly on this property of clay. In the past, the universal practice has been to consider warpage as a shrinkage trouble; that is, a clay with a high shrinkage would be expected to warp badly. In a general way, this may possibly be true, but such a theory leaves very much to explain in studying warpage.

By the term viscosity is meant the degree of fluidity of the clay, in flowing or bending while under heat. For instance, tar is said to

be a fluid of high viscosity, while water compared to tar is of low viscosity, and alcohol is of still much lower viscosity than water. In silicates, the viscosity of the slag of a charcoal iron furnace is of a high order, since it creeps out slowly, inch by inch, over the open hearth, and is being broken up and carted away as a glassy solid at the other end of the slag-stream, only a few feet from the point where it has issued from the furnace. A coke blast furnace, on the other hand, produces a slag of low viscosity, which flows like a fiery torrent through the cinder runways, but chills almost at once from a thin fluid to a solid. A few per cent. difference in the ratio of silica, alumina and lime produce these remarkable variations in viscosity.

In the same way, clays with a high degree of viscosity would be expected to resist warpage, while ones with a low viscosity, i. e., a thin fluid fusion, lend themselves very freely to this trouble. On the theory that chemical and mineralogical composition are instrumental in this defect, the following references were found bearing more or less directly on the situation:

Influence of Feldspar.—That complete vitrification is not necessary to the development of warpage has been shown by Day and Allen.[1]

The above writers in an attempt to study the viscosity of feldspars at their melting point prepared slivers of the feldspars about one by two by thirty millimeters. These slender trials were then spanned across small empty platinum crucibles, and placed side by side in the furnace. These exposed crystals were heated to 1,225° C. for three hours. When removed, they were completely amorphous (melted), but retained their position with hardly a trace of sagging. Other slivers were heated in some instances to 1,300° C. for a few moments, and while at this temperature a platinum rod was inserted through a hole in the top of the furnace, and allowed to rest as a load upon the middle of the crystal bridge. Under this load, the slivers gradually gave way. Slides cut from these trials showed no squeezing out of the melted portion between the crystal fragments on the side towards the center of curvature, or open cracks on the outer side. On the other hand, there was evidence of the bending of the crystals as well as of the vitreous portion.

They further say, with a degree of confidence, that the order of magnitude of the viscosity of the molten portion is the same as the rigidity of the crystal at these temperatures.

From the above, it has been shown that while the feldspars had completely fused or melted, their viscosity was so high that deformation did not take place until a load had been applied.

While Day and Allen have shown that pure crystals of feldspar are extremely viscous, the actions of these same feldspars in connec-

[1]Am. J. Sci., Vol. 169, page 93.

tion with a mineral mixture like ordinary clays might be very different. In the latter case, the feldspar might have an affinity for some portions of the mixture, and form fluid compounds that might possess a low degree of viscosity, which in turn might be imparted to the whole mass, causing warpage.

Again, it might be possible, under some conditions, for the glass, formed by the fusion of the feldspar, to drain to the lower parts of the mass, leaving the upper portion unfused and porous. The well known "liquation" of platinum-gold alloys, in which the gold drains to the lower portion of the mass, leaving a platinum skeleton above, is a case in point. The silicate skeleton thus remaining might possess rigidity enough to overcome the low viscosity of the fluid matrix in the lower sections, and thus prevent warpage. In this manner, it might be possible to have a considerable degree of vitrification in a clay unattended by warpage.

The action or influence of feldspar upon an ordinary clay is unquestionably a matter of condition, depending upon the size of the grains of feldspar and their relation to the other ingredients. Should the feldspar be present in relatively large grains, its influence would largely be that of resistance to warpage, while the same quantity of feldspar finely pulverized and intimately mixed throughout the mass could cause a rapid reduction in the degree of viscosity of the clay as a whole.

Influence of Mica.—In the past, mica has in general been considered to act as a flux to clays, after the manner of feldspars; it has, however, been proved that its action upon clay will depend very largely upon the size of the grain.

Stull[1] has shown that mica when extremely fine-ground acts as a flux upon clay, but not to the same extent as feldspar. In large flakes, however, it may act directly opposite. It is not at all uncommon to find flakes of mica remaining unaffected in hard-fire biscuit ware. proving that in large grains mica does not act as a flux at cone 8. Thus, if distributed throughout a clay mass in relatively large pieces, it may have a strong action upon the viscosity of the clay by its slowness to react with the other ingredients. Mica taken alone requires about cone 13 to melt it, as shown by Rieke[2]. When present in ordinary clays or shales, burning at or near cone 1, it is therefore not likely that mica assists very greatly in softening the body, but is more apt to increase its degree of viscosity, as a sterile ingredient.

Influence of Alumina.—Purdy[3] says, "Alumina not only raises the actual period at which fusion is completed, but also causes the

[1]R. T. Stull, "The Fluxing Power of Mica in Ceramic Bodies." Trans. Am. Cer. Soc. Vol. IV., p. 255.

[2]Rieke, R.—"The Action of Calcium Mica on Kaolin." Sprechsaal, 1908, 577.

[3]Purdy, R. C.—"Further Studies on White Bristol Glazes." Trans. Am. Cer. Soc. Vol. V., p. 136.

ware made from aluminous clays to soften and deform very slowly. The slower softening and deformation of ware made from aluminous clays has been attributed to viscosity of the mass caused by alumina."

The same writer[1] has shown that the addition of alumina as a constituent in a stone ware glaze, up to a proportion of alkali and alkaline earths to alumina of 2.5 to 1, not only rendered the glaze more fusible, but also less viscous.

Additions of alumina above this proportional amount, however, increased the refractoriness of the glaze, and its viscosity.

It is a well known fact that additions of alumina in slags and glasses above certain limits or proportions will increase their viscosity.

Frink[2] says that glass containing 0.6 per cent. or less of alumina will be found to be considerably less viscous than glass which contains from 3 to 4 per cent. of alumina. The latter glass, due to its greater viscosity, will be tenacious and more desirable to work, and will show a less tendency to retain the imperfections of the moulds.

Thus, the manner that alumina may act upon viscosity will depend upon its relative proportion to the other substances present.

Influence of Magnesia.—In a paper by Hottinger[3] it was pointed out that magnesite or dolomite added to a shale very greatly widened its vitrification range, as shown by the following table:

TABLE No. 29.

Hottinger's Experiment on the Influence of Magnesite upon the Fusibility of Clay.

No.	Mixture.	Absorption.			
		Cone 05	Cone 1	Cone 3	Cone 5
C 1	Shale 100, Whiting 25 ..	21.9	Melted ..	Melted ..	Melted.
C 2	Shale 100, Whiting 12.5	20.4	Vitrified..	Melted ..	Melted.
C 3	Shale 100, Magnesite 21.	32.8	7.3	Vitrified..	Shape retained.
C 4	Shale 100, Magnesite 10.5	28.4	0.32	Vitrified..	Slightly swelled
C 5	Shale 100, Dolomite 22..	22.4	11.5	Partially melted.	Melted.
C 6	Shale 100, Dolomite 11..	17.7	12.1	Blistered	Melted.
	Shale without additions.	12.0	0.78	Blistered	

[1]Purdy, R. C.—Illinois Geol. Survey, Bull. IX, p. 217.

[2]Frink, R. L.—"The Effect of Alumina on Glass." Trans. Am. Cer. Soc. Vol. XI, p. 99.

[3]Hottinger, A. F.—"The Influence of Magnesia on Clay." Trans. Am. Cer. Soc., Vol. V, p. 130.

From the preceding tab'e it is evident that mixtures C3 and C4 are strongly viscous, though vitrified completely. At cone 5 they have retained their shape, while mixtures of the same shale with whiting melted completely at a lower temperature, and with dolomite the action was intermediate in severity. Hottinger further says, in reviewing the previous work of Mäckler[1] on the same subject, that clays carrying high magnesia can be made into wares of extreme length, with very thin walls, which may be very nearly vitrified, and still be kept perfectly straight and true. Also, the district in which Mäckler made his first observations on the effect of magnesia was a roofing tile district, and the tiles produced from the clays of one part of the district warped badly, while clays from the other part of the district did not. Mäckler found the magnesia content to be the only important difference in composition, and later verified by synthetic experiments the role of magnesia in reducing warpage.

It is believed that these results are due to the extreme viscosity of the magnesium silicate compounds, which allow a more complete vitrification without failure.

That many red-burning clays and shales in this country contain magnesia in various quantities, even up to several per cents., is a well known fact. Thus, it is quite possible that magnesia is playing a larger part in the prevention of warpage than is commonly supposed.

Influence of Lime.—The influence of lime upon the warpage of a clay will be dependent upon its size of grain and distribution. When present in lump or granular form, it is not probable that it assists warpage any more than any other particles, but when incorporated throughout the mass in large quantity and a finely divided state, it tends to keep the body porous and to delay shrinkage and vitrification and to hold the body free from warpage up to the point where combination begins. From thence, it causes the body to soften with extreme rapidity. Such warpage as occurs in this connection is palpably that of imperfect fusion.

In clays containing small amounts of lime (5 to 10 per cent.) finely divided and evenly distributed, its action is towards early fusion and rapid failure. The action is the same in quality, but the temperature at which it occurs depends on the quantity of lime, being low for low lime, or high for high lime.

Experimental Work on Warpage—With the foregoing general knowledge of the trade conditions as to warpage, and the theoretical discussions just quoted as to suggested relationships between mineral composition and warpage, some practical tests of the relative warpage of actual roofing tile clays was taken up. No records of any actual measurements or tests of warpage could be found, and therefore the method of inves-

[1]Mäckler, Dr. H. Influence of Magnesia on the Behavior of Clays, Tonindustrie-Zeitung, Vol. 26, II, p. 705.

tigation was necessarily entirely original and tentative. A large amount of the work which has been done in the testing of the standard roofing tile clays has been directed to the measurement of this property, so as to be able to pick out those clays which warp, or tend to warp, badly. Three separate experiments were made upon each clay in the series, excepting O and L, of which the supply of clay secured was insufficient.

First Experiment on Warpage.—It was thought that much could be told of the likelihood of the clay to warp by making thin flat tiles or quarries, and burning them upon flat surfaces, and noting the amount of "dishing," i. e., the curling up of the sides of the tiles, forming a shallow concave surface.

For this test, tiles one-half inch by four and one-fourth inches by four and one-fourth inches were made, by batting out blanks of approximately the correct thickness, then cutting them to a size that would just enter the die of a screw-tile press. The blanks were carefully pressed, especial attention being paid to getting them all as nearly of the same thickness as possible.

After pressing, the tiles were carefully placed upon selected straight boards, or pallets, where they were left until completely dry before handling, in order that no undue strains might be introduced. When these tiles were dry, they were set upon especially selected fifteen inch by twenty inch fire clay slabs, and placed in the chamber of a coke-fired down-draft kiln having a capacity equal to about 300 bricks. In order to obtain as much dishing as possible, it was thought best to place these trial pieces in the upper part of the chamber, where they would receive the direct action of the heat.

In order to learn the time at which warpage occurred, a series of four separate burns was carried out, finishing at cones 09, 07, 04 and 01, respectively. It was the intention to stay within the workable temperature limits of the clays, hence no burns were made above cone 01.

The time spent upon each of the four burns was about thirty hours. While more time would possibly have been better, it was firmly believed that the most severe test to which a badly warping clay can be put is a short, rapid firing, which does not give time for proper equalization of the strains.

After assembling the trials from the four burns, they were studied to note their amounts of dishing. Instead of being "dished," they were, with very few exceptions, "bowed"—that is, the center of each tile had raised or drawn up, while its sides or edges rested upon the fire clay slab which formed the floor.

In order to measure the amount of "bowing," a shallow, open-topped box a little larger than the tile was taken, and over the top from side to side a fine silk thread was stretched taut. A tile was placed in

the box, with the convex side up. Then, with a millimeter scale graduated to 0.25 mm., a direct measure was made from the thread to the center of the convex surface and then to the two edges directly under the thread, thus obtaining a difference in reading, dependent upon the amount of convexity.

In order to compare the amount of dishing or bowing in the different clays, all measurements were figured in per cents of the total distance from the silk thread to the box—that is, the measurement from the thread to the top of the tile was subtracted from the total depth from thread to the floor of the box. This amount was divided by the total depth, this quotient multiplied by 100, giving the figure in per cents of the total distance.

While it was assumed that the tiles were all of one thickness, it is true that there were slight differences due to the differences of shrinkage, but no allowance was made for this.

On tabulating these data, (Table 30) it was observed that clays which were known to warp badly in actual practice gave here different results under different heat treatment. For instance, clay G has at cone 07 bowed 1.56 per cent., at 04 it is straight, and at 01 it developed a dishing of 6.25 per cent. In other words, it would appear that at cone 04 the clay has so softened that it has straightened out, and yet at a higher heat it curled again in the opposite direction. In clays L, N, K, G, B, M and C there have developed both dishing and bowing of the trials. Just what conditions prevailed in the tiles or in the firing to produce such irregular results cannot be said.

There appears to be very little relation between shrinkage and warpage, as shown by clays A and E against clay G. The two clays A and E have a relatively high total shrinkage, and have remained straight, while clay G, having a rather low total shrinkage, has developed considerable warpage. Clay B, with a very low shrinkage, has warped to a considerable degree at the higher temperatures tested.

In a general way, it will be seen that those clays which warp badly in this test, such as J, K and L, warped badly in the succeeding tests, also. But this test did not seem to give a satisfactory expression to the tendency of clays to warp, and another test was devised to take its place.

Second Experiment on Warpage.—Much trouble results from a difference in the burning shrinkage of the two ends of auger-made Spanish tiles. The cause of the trouble is due largely to the method of setting the tiles in the kiln. As stated elsewhere in this report, auger-made Spanish tiles are set standing on end, in open fire-clay boxes or saggers. After burning, the end of the tile that was down is very often found to be larger, and its curvature more flattened out, than the end which was uppermost. The cause of this is the restriction of the shrinkage by friction against its supporting surface, while the upper end had perfect freedom to shrink or warp without restraint. It was thought worth

TABLE No. 30.

Showing Results of First Warpage Experiment on the Standard Roofing Tile Clays.

Temperature in Cones.	Designation of Clays.													
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
09	0.00	0.00	1.04*	0.00	0.00	1.04	0.00	2.61	0.00	2.61	5.73	0.00	1.56	1.04
07	0.00	0.00	1.05	0.00	0.00	3.13	1.56	1.04	0.00	1.04	0.00	1.05*	0.00	0.00
04	0.00	1.04	4.69	0.52	0.00	0.00	0.00	0.00	1.04	1.04	1.03*	0.52*	0.00	0.52*
01	0.00	2.08*	1.57	1.04	0.00	2.61	6.25*	1.04	2.09	7.29	8.33	9.37	1.56*	3.13*

*Concave or "dished." Other determinations show amount of convexity.

while to make this industrial difficulty the basis of a test of the comparative warpage of different clays. A set of trial pieces was prepared, of such shape and thickness that it was thought that the clays likely to to give trouble in practice would be sure to develop it. These trial pieces were made in the form of half-round tiles, or semi-cylindrical troughs, three and one-fourth inches long, with an outside diameter of three inches and one-fourth of an inch thick. They were made by pressing the clay by hand in plaster molds, much care being taken to produce them free from flaws. In order to prevent their becoming distorted while drying, pallets were made, upon which cleats were nailed just far enough apart to allow the sides of the half-rounds to stand between them. They were thus prevented from spreading or settling down while plastic.

After thoroughly drying, the trial pieces were carefully measured at each end, one end being marked. The trials were then set in the kiln, each standing free from its neighbor on a smooth fire-clay slab.

Fig. 32—Showing Trial Pieces for First and Second Warpage Experiments, in place.

It was thought that the upper or free end would draw in, while the lower end, due to its friction on its support, would be prevented from doing so, and thus giving a measurement of warpage. The trials for this test were burned in the same manner, at cones 09, 07, 04 and 01.

After obtaining the trials from the four separate burns, they were again carefully measured at both ends. Then dividing the difference between the unburned and the burned measurements by the initial

width, and multiplying by 100, gives the per cent. of contraction in width. As will be seen in table No. 31, there is in most cases a marked difference between the per cent. of contraction of the lower and upper ends.

This experiment would, no doubt, have proved more successful if the trial pieces had been made much larger and longer, increasing the load upon the lower end, and thus making the resistance to warpage greater. The thickness of the walls of the trial pieces should also have been increased, to prevent their bulging out. In the majority of the

TABLE No. 31.

Showing Results of the Second Warpage Experiment on the Standard Roofing Tile Clays. The Difference in Contraction of the Free and Restrained Ends of Half-round Tiles.

Designation of Clay.	Cone 09			Cone 07			Average.
	Per cent. Contraction Upper End of Tile.	Per cent. Contraction Lower End of Tile.	Difference.	Per cent. Contraction Upper End of Tile.	Per cent. Contraction Lower End of Tile.	Difference.	
A	1.59	1.59	0.00	2.63	1.82	0.81	
B	0.68[1]	0.139[1]	0.541	0.83	0.27[1]	1.10	
C	0.972	0.110	0.862	3.01	2.31	0.70	
D	0.481	0.278	0.203	0.27[1]	0.69[1]	0.42[2]	
E	0.744	0.604	0.104	0.59	0.89	0.30[2]	
F	1.25	1.06	0.19	1.09	1.91	0.82[2]	
G	0.55	0.41	0.14	1.32	1.87	0.55[2]	
H	0.291	0.298	0.007[2]	2.36[1]	2.21	4.57	
I	0.41[1]	0.55	0.96	0.70[1]	0.27	0.97	
J	3.35	4.58	1.23[2]	1.54	1.12	0.42	
K	3.38	2.54	0.84	5.15	1.77	4.38	
L	2.59	1.45	1.14	4.57	2.34	2.23	
M	....	....	....	0.82	0.13	0.69	
N	5.20[1]	5.28[1]	0.08[2]	3.43	3.83	0.40[2]	
	Cone 04			Cone 01			
A	8.13	6.57	1.56	9.41	4.48	4.93	1.82
B	2.06	1.51	0.55	3.90	3.01	0.89	0.512
C	16.32	12.06	4.26	9.27	9.33	0.06[2]	1.470
D	8.31	2.84	5.47	1.75	1.62	0.13	1.55
E	0.86	0.714	0.146	4.83	3.94	0.89	0.038
F	3.71	1.65	2.06	7.92	6.52	1.40	1.117
G	6.07	4.84	1.20	4.41	0.666	3.75	1.41
H	0.00	1.16[1]	1.16	3.91	3.24	0.67	1.60
I	1.25	1.67	0.42[2]	2.13	1.43	1.70	1.01
J	16.94	15.05	0.89	0.43	5.78	5.35[2]	1.97
K	1.30	2.32	1.02[2]	13.46	7.91	5.55	2.94
L	6.58	4.76	1.82	4.01	3.76	0.25	1.36
M	0.82	1.54	0.72[2]	5.79	0.41	5.38	2.26
N	1.16	0.57	0.59	0.54	0.24	0.30	0.34

[1] Expansion, instead of contraction.
[2] Per cent. that the bottoms have contracted in excess of the tops.

cases where a greater contraction of the lower end than the upper was shown, it was due to the sides bulging out and spreading the upper end, while the lower end was held by friction from doing so. Again, it is quite possible that the personal factor in pressing such thin sections has played an important part in causing irregularities.

In studying the results of the second warpage trials it will be seen from the column of averages in the table that clay K has shown the greatest degree of difference between the two ends of the trials, pointing out this clay as the one most likely to give trouble from warpage. The results of this test on clay K have been confirmed by both of the other warpage tests.

In a comparison of the fire shrinkage and warpage, it is very clear from the behavior of clays K and C in this method of testing, that there is no relation between the numerical values of the properties in different clays. Clay K has a fire shrinkage at cone 01 of about 9 per cent. and has shown a warpage of 2.94 per cent. Clay C at cone 01 shrinks in the neighborhood of 8 per cent. and only shows a warpage of 1.47 per cent., or just one-half that of K.

Clays C, D, G, H and I show very similar warpage in the above test, and these same clays have fallen quite closely together in the two other tests for warpage as well. Clays M and B give erratic results in this test. It is believed, in the light of the third warpage test, that the figures for these clays are not representative, and that B and M should be classed with clays like C and D, while B as here shown belongs with clays E and N, and M with K. The clays E and N show a very low degree of warpage, but their high lime content, their slow vitrification habit, their porosity until nearly ready to fuse, and the suddenness of their fusion when it once begins, all show that their behavior would not be like the vitrifying clays composing the rest of the series.

All things considered, the second method seems to have but little advantage over the first, and neither are satisfactory.

Third Experiment on Warpage.—The third experiment more nearly approaches a correct method for measuring the warpage tendency of clays than does either of the others tried, and it is believed than any other method known at the present time. It consists in supporting a long bar of clay on knife-edges in the kiln and measuring the amount and rate of sag developed in burning.

It is believed that Dr. E. Cramer, of Berlin, Germany, was the first to use this method in the study of clays. The Holdcroft thermoscope, a patented English pyrometric device, closely resembling the German Seger cones in composition, uses exactly the same principle in its test bars, which are laid horizontal on supports, and which betray fusion by sagging, instead of curling over as the triangular pyramids called "cones" do. It is not known, however, that this idea has

ever been used in this country prior to this investigation, or for this purpose.

The work as carried out consisted in passing the previously tempered clays through the Mueller auger machine and out through a flat shingle die, in a bar one-half inch thick by six inches wide. As the bar of clay issued, it was cut crosswise into thirteen-inch lengths, which in turn were cut lengthwise into strips one and one-fourth inches wide by thirteen inches long, after being placed upon a pallet. No handling of the small thin strips of clay after cutting was necessary. Much care was taken to select perfectly straight pallets upon which to dry these bars. In order to avoid drying strains as much as possible, the trial bars were all carefully dried in an open room until they were white-hard, after which they were placed in a drying-oven while still on the pallets. When dry, they were taken to the coke-fired down-draft kiln mentioned before, and placed for firing. It is in the method of setting that the real test of the clay consists.

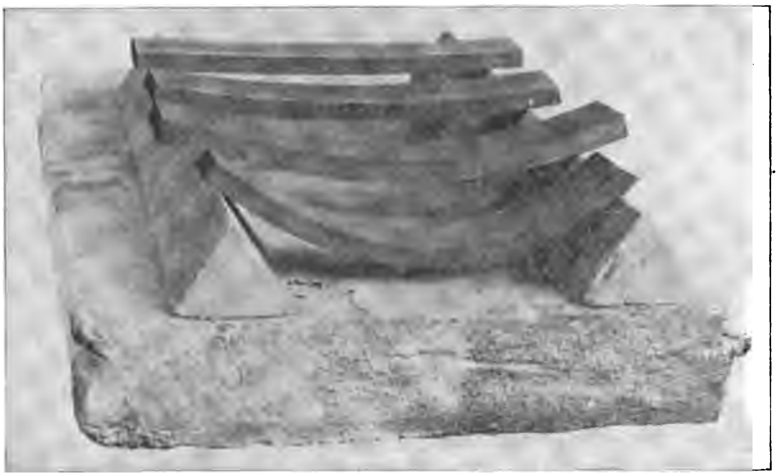


Fig. 33—Method of Setting Warpage Trials on Supports.

From the above cut it will be seen that the trial bars were set upon fire-clay knife-edges (previously burned) placed 10 inches apart, center to center. The trial bars, which had been thirteen inches long when first cut, were for the most part about twelve inches long at the time of setting. Hence, with the knife-edges ten inches apart, there was an overhang of about one inch at each end for every bar. Two trial bars of each clay were set for each burn. While purposely not placed side by side, the two trial bars gave closely concordant results in every instance. In the four burns made, at cones 09, 07, 04 and 01, res-

pectively, it was the intention not to overfire any of the clays and keep within commercial temperature ranges for all of the different clays.

These test bars, one-half inch thick by one and one-fourth inches wide by ten inches long between supports and twelve inches, more

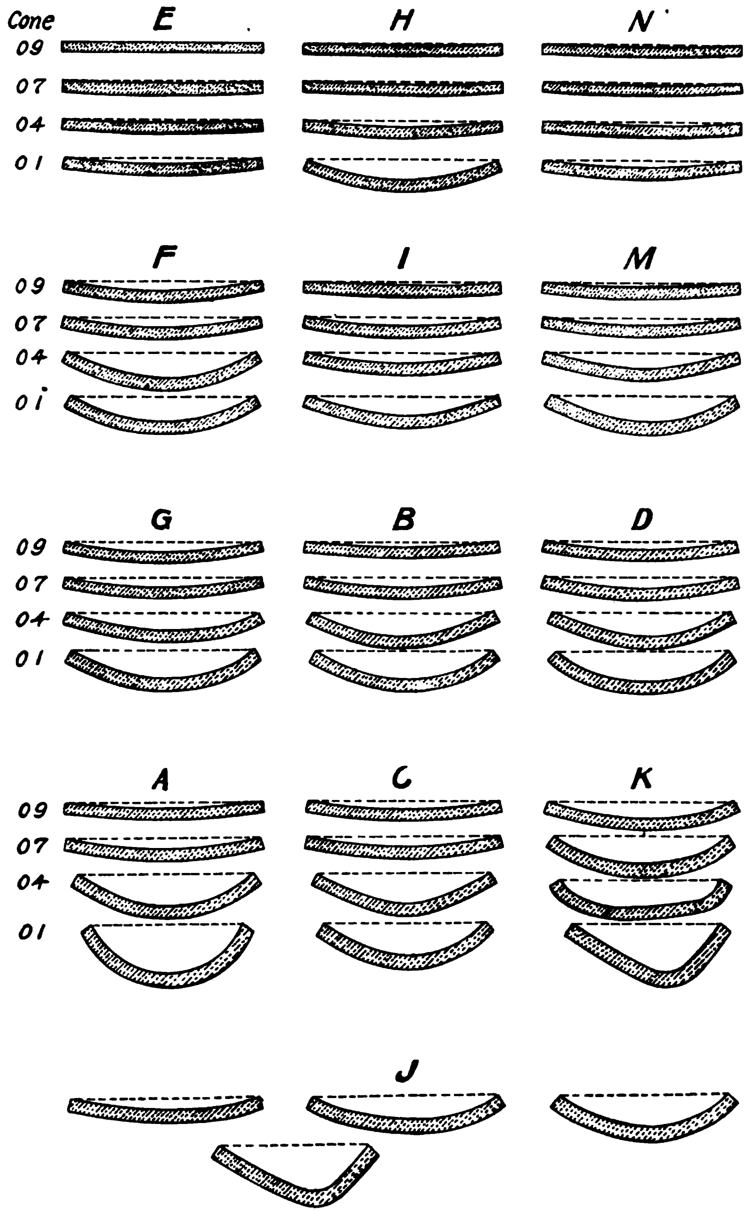


Fig. 34—Drawing Showing Sagging or Warping of Clay Bars at Different Temperatures.

or less, over all, naturally tended, on softening from the heat, to sag down in a more or less perfect arc of a circle, of which their original position formed the chord. The idea of the experiment was that the amount of the sag would afford a numerical index of the warping tendency.

In measuring the trial bars, it was assumed that they went into the kiln perfectly straight, i. e., with 0 per cent. warpage. The degree of sagging found after burning was measured by taking a thin flat rubber band and stretching it tightly from end to end of the tile across the intervening space like the string to an archer's bow, as shown by the dotted lines in Figure 34. Then by means of calipers graduated to the second decimal place, the distance from the under side of the taut band to the upper surface of the tile at the point of greatest deflection was taken, thus giving a direct measure and comparison of the warpage in the different clays.

After taking the above measurements, a two-inch piece was carefully broken from one end of each trial bar, and the porosity was determined with great care by the methods given in that connection.

The tables to follow have been prepared by taking the average of the two results for each clay for each burn, for the degree of warpage and for the per cent. porosity. The linear shrinkage figures were not available at cones 09, 07 and 01, and were interpolated from the table given under the head of "Fire Shrinkage." For cone 04 the observations required no interpolation.

In the above cut, the trial pieces are represented in their different degrees of warpage from a straight line at the four heat treatments, cones 09, 07, 04 and 01, respectively.

Clays E and N have deformed the least and at a slow rate. Clays K and J developed a very high warpage and at a rapid rate, i. e., the increase from cone to cone was decided. Clay A shows a warpage equal to J or K, but there has not been a decided failure of this clay as in clays J and K. It will be noted that they have sagged in irregular curves, while A has sagged in a very regular manner. Clay K was observed to deform badly by the time that the kiln had reached a dull-red heat, indicating very early changes under fire. The discrepancies of clay K in this and other tests before recorded, compared to the other clays tested, are probably due to the fact of its very early vitrification. Its curves of porosity, shrinkage and specific gravity are not different from the other curves in kind or contour, but the latter half of its vitrification period falls in the same temperature zone that witnesses the first half of the vitrification in the other clays. The result is that it seems all out of joint with the others. Without doubt, its full curves would be more normal in contour if our observation had begun at 750° C. instead of 950° C. (cone 010).

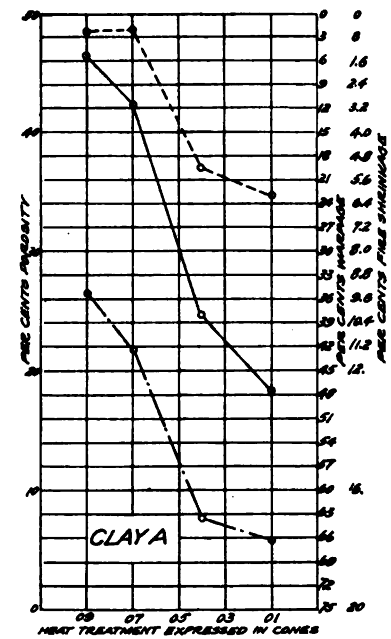
In the following tables are given the warpage as determined by this method. In addition, the fire shrinkage and porosity are given to facilitate comparisons.

TABLE No. 32.

Shosing Results of Third Warpage Test on the Standard Roofing Tile Clays, with Results of Fire Shrinkage and Porosity Tests Added for Comparison.

Designation of Clay.	Temperature of Different Burns. Cone 09			Cone 07		
	Per cent. Fire Shrinkage.	Per cent. Porosity.	Measure of Warpage.	Per cent. Fire Shrinkage.	Per cent. Porosity.	Measure of Warpage.
A	0.55[1]	26.49	5.27	0.55	21.71	11.80
B	0.12	26.24	5.57	0.87	19.26	12.55
C	0.45	32.72	5.95	1.25	28.44	10.92
D	0.05[1]	31.79	7.47	0.10	32.20	10.87
E	0.20[1]	39.54	0.00	0.30[1]	29.01	1.80
F	0.55[1]	31.05	8.10	0.05	30.11	11.22
G	1.00	25.28	8.50	2.87	23.83	11.12
H	0.20[1]	31.03	1.87	0.10	30.35	3.02
I	0.50	30.07	5.87	0.50	29.90	12.00
J	1.50	16.81	8.40	3.00	10.56	20.10
K	3.24	16.27	17.75	5.19	10.19	37.95
M	0.25[1]	30.96	6.10	0.55	28.03	10.15
N	0.00	36.32	1.32	0.00	36.13	1.62
	CONE 04			CONE 01		
A	5.15	7.57	38.02	6.10	5.75	47.15
B	2.00	11.81	29.50	2.25	11.74	42.00
C	6.00	11.86	36.75	7.20	8.81	47.15
D	3.50	28.74	21.82	5.62	23.01	41.30
E	0.20	38.34	2.47	2.20	34.88	8.60
F	3.35	22.42	24.95	4.52	18.91	41.55
G	4.50	12.75	32.15	5.25	10.70	41.55
H	1.70	29.20	8.27	2.90	26.02	24.80
I	0.50	31.29	15.02	0.62	25.13	25.40
J	5.50	2.99	35.50	5.75	2.82	61.15
K	7.79	6.65	37.30	5.89	2.78	62.00
M	1.55	25.73	19.25	2.42	22.26	40.50
N	0.50	37.91	4.55	1.50	37.57	5.75

These results have been plotted in the following curve sheets (pages 147-150). For convenience in observing, the warpage and fire shrinkage are made to read *down the page*, while the porosity *reads up*. By this expedient, all the curves are made to traverse the paper in the same direction. Also, the scale selected for each kind of data is different, and is chosen to make the curves change elevation at about the same rate *in the average case*. If one property changes faster than another, the curves immediately diverge.



In each of the following seven diagrams, the upper curve, platted in dotted lines, represents the fire-shrinkage. The middle curve, in solid lines, is the warpage data, and the lower curve, platted in broken lines, represents the porosity.

Fig. 35—Warpage-Porosity-Shrinkage Comparison for Clay A.

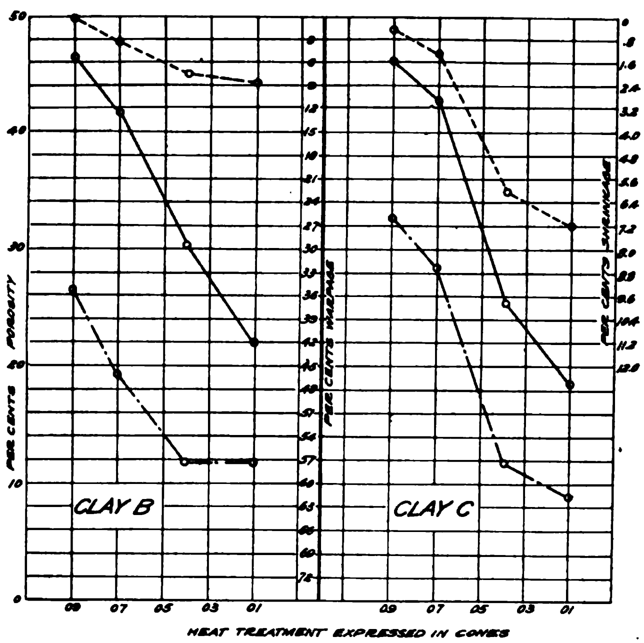


Fig. 36—Warpage-Porosity-Shrinkage Comparison for Clays B and C.

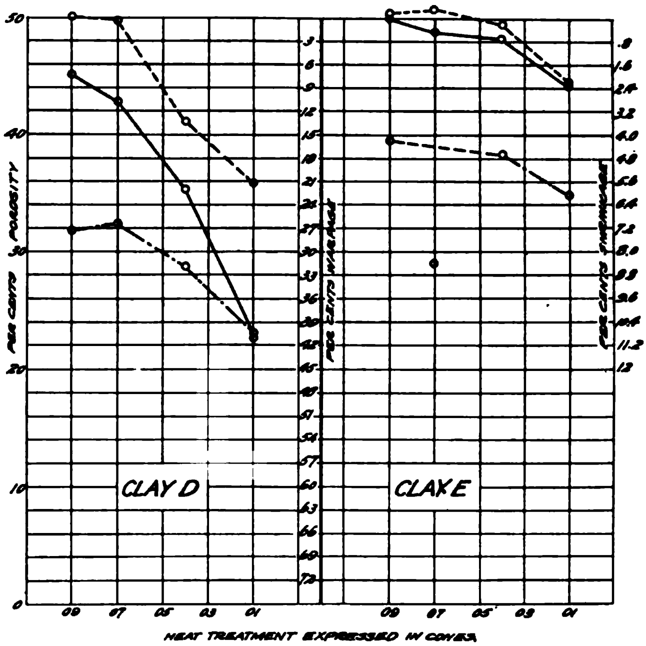


Fig. 37—Warpage-Porosity-Shrinkage Comparison for Clays D and E.

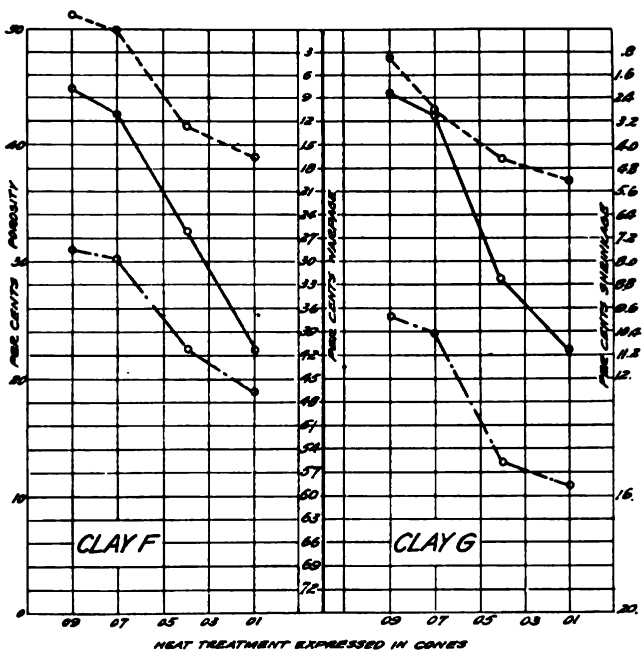


Fig. 38—Warpage-Porosity-Shrinkage Comparison for Clays F and G.

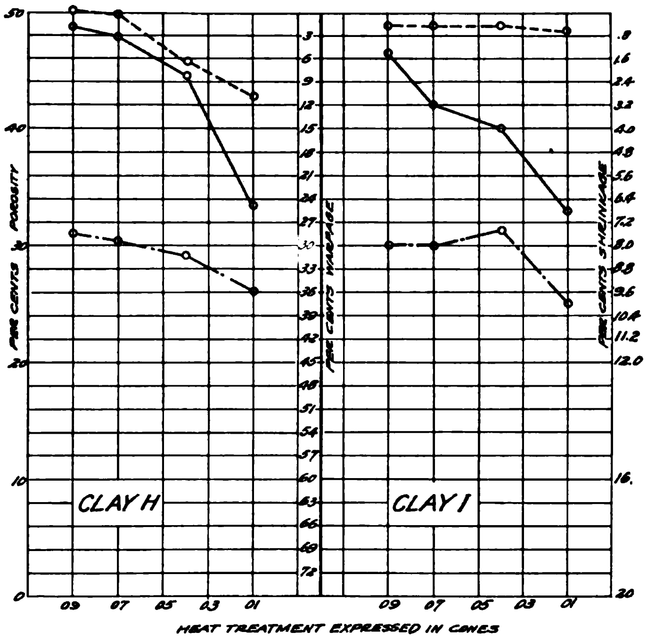


Fig. 39—Warpage-Porosity-Shrinkage Comparison for Clays H and I.

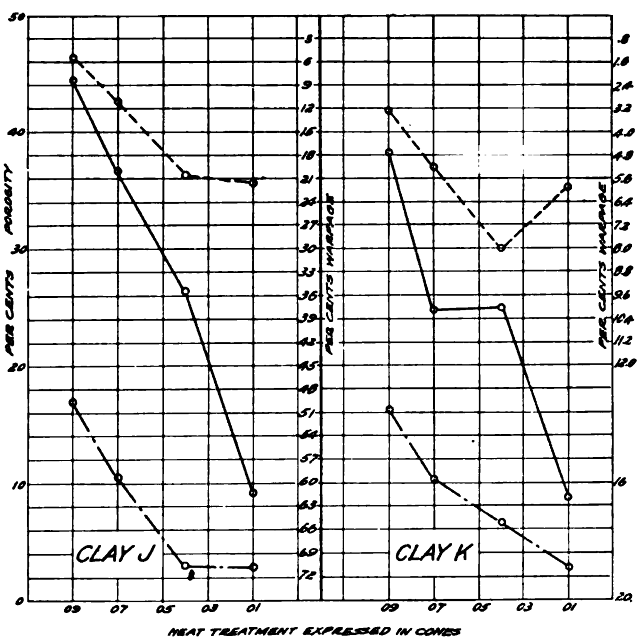


Fig. 40—Warpage-Porosity-Shrinkage Comparison for Clay J and K.

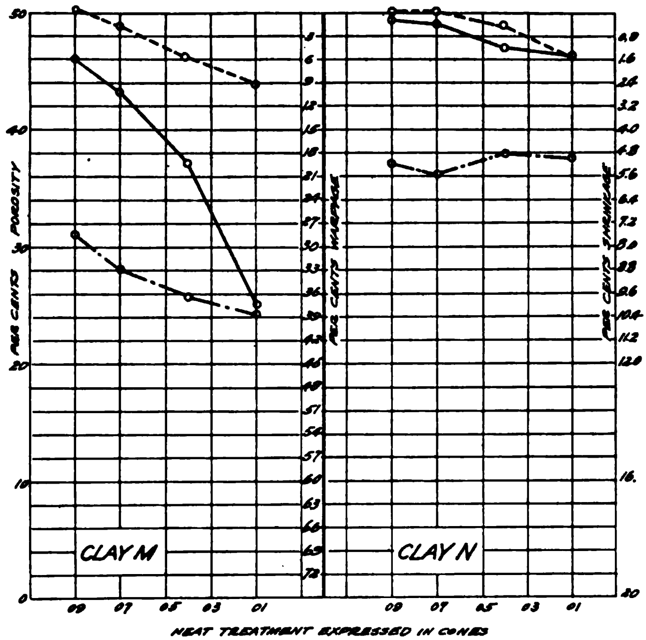


Fig. 41—Warpage-Porosity-Shrinkage Comparison for Clays M and N.

A careful study of these curves reveals the close relation which exists between the changes of volume and the changes of form. This is as has been assumed and expected, but up till the present no proof had been submitted, so far as is known.

There are, it is true, some puzzling inconsistencies in the data. These inconsistencies largely come, no doubt, from the fact that we are dealing with a very small number of trial pieces, and, as is well known, shrinkage data are notoriously erratic and can only be accepted as of much weight when they are the mean of a large number of determinations. The wonder is, therefore, not that there are inconsistencies, but that so much consistency can be gotten out of such a limited amount of material.

The three kinds of curves in clays A, C, E, G and N show a marked concurrence in direction and rate of change. No one, after looking at them, can fail to be struck with this fact. Clays A, C and G are all clays which shrink rather highly, decrease in porosity rather sharply, and warp rather evenly, but in considerable amount. Clays E and N are calcareous clays, which do not enter their active vitrification process in the temperature zone studied, and therefore neither warp nor shrink nor grow dense. They prove nothing, either pro or con, in this discussion.

In the clays D, F, H, J, K and M, we find again a marked concurrence between the rates of fire shrinkage, porosity extinction, and warp-

age, in the earlier portion of the temperature zone studied. Between cones 09, 07 and 04, the concurrence in direction and rate of change is marked. But between cones 04 and 01, the warpage consistently changes faster than the other properties do.

This might be construed as weakening the contention that warpage is a function of the vitrification process, and controlled by the same actions that control shrinkage and porosity, but in fact it strongly verifies and supports it. If we consider warpage as being the result of incipient fusion of the clay—the development of a viscous taffy-like material in the clay body, not sufficient in amount to cause the clay to actually liquify and lose its shape at first, but growing gradually in amount and fluidity as the temperature rises, until in the end it does cause the resistant frame-work of the clay to slump and the clay to fuse—then the increase of warpage more rapidly than the parallel changes in either shrinkage or porosity is the normal thing and should be expected.

We know that, as the porosity of an ordinary clay is extinguished, the rate of change becomes less and less with each increase of temperature. The progress goes on rapidly when the porosity is high, but gets slower and slower as it approaches the maximum density. Similarly with fire shrinkage. The maximum, in good clays at least, is reached by a series of slow approximations, followed by slow bloating, and the volume curve runs nearly horizontal for a time. But, while the last of the shrinkage and porosity are gradually taking place, the viscosity or incipient fusion is all the time gaining in force and power. Naturally, as the temperature rises to more and more critical points, do the warpage and deformation increase. It would be seen to increase still faster in proportion, if the temperature zone studied in this work had covered a still higher range. Curves D, F, H, J, K and M, therefore, represent the same thing as curves A, C, and G, except that they have gone a little further toward fusion, and the deformation between 04 and 01 has made more headway in the former than in the latter three. This is especially clearly distinguishable in clay J. Here we have the most complete extinction of porosity, with high fire shrinkage, that we have in the available data, and with it we get the highest deformation, and *the most marked increase in rate of warpage when the other properties have ceased to change.* In K, bloating has begun at cone 01, and this destroys the symmetry of the curves, though it would explain the high warpage.

In two of the thirteen clays examined, viz., B and I, we find the situation less easily read. B is remarkable only in its very low shrinkage. Its porosity curve and its warpage behavior are strictly concordant with most of the other samples tested. But how a clay can show such evident signs of viscosity with so little fire shrinkage is not understood.

In clay I, the curves indicate that the vitrification process was quiescent up to cone 04, neither fire shrinkage nor reduction of the porosity occurring. During this time a moderate or small warpage took place. At cone 04, porosity suddenly decreased, concurrent with warpage, but the fire shrinkage was still not affected. It is probable that a study of these clays over a wider temperature zone would assist in understanding their behavior.

From the foregoing, we may present the following general deductions:

First—Change of shape in the burning of a clay ware is a function of the vitrification process, and results from the formation of a viscous silicate matrix, while the principal part or skeleton of the clay is still solid.

Second—The changes of shape which occur early in the burn, while the clay ware still retains its general shape and usefulness, and those late changes from overfire which destroy the shape for commercial uses, are stages of one and the same process.

Third—Changes of shape are found to begin at temperatures far lower than was expected—a low red heat in one instance. In general, these changes are insignificant below cone 010.

Fourth—The rate of change of shape in normal clays is closely parallel to the rate of the other vitrification changes (shrinkage, porosity etc.) for a time. In most of the clays tested, this parallel lasted to cone 04 and in several to cone 01. But as the rate of shrinkage and porosity changes decreases on approaching completion, the rate of change of shape increases, so the curves do not remain concurrent at higher temperatures.

Fifth—The tendency to warpage and the absolute amount or numerical value of the warpage of a clay at any given temperature are inherent properties of the material, and do not admit of prophecy: i.e., knowledge of the behavior of one clay does not justify us in assuming what the next clay will do. Warpage stands on the same plane in this respect as the other properties of a clay. Nor can warpage be correlated at all closely in numerical amounts with the shrinkage, porosity, or other properties of the clay. For instance, two clays of equal warpage may or may not agree closely in shrinkage or porosity. Likewise, clays having the same shrinkage or porosity may or may not have similar warpage. Also, while high shrinkage and low porosity incline us to expect high warpage, it does not always follow—the relation is only a general one.

Sixth. In studying warpage of clays for commercial applications, trial pieces covering the entire temperature range from cone 010 or below up to the point of complete maturity or slight overfire should be secured, in order to determine the critical point where the deformation begins to take place at a faster rate than the concurrent changes in

shrinkage and porosity. This point indicates where the warpage may be expected to become severe.

Seventh. In estimating the value of clays for roofing tile purposes, or for making any thin-walled wares, the determination of the warpage tendency is a practical test, second in importance only to color and vitrification range.

SUMMARY.

In deciding on the clay to be used in a new enterprise, where all the data have been obtained that can be obtained as to its properties, a decision must be reached as to whether to accept or reject it. Enough has been shown in the foregoing series of tests to show that very rarely is any clay tested of which the properties are all favorable. Some defect is almost certain to be present. The question is where to draw the line between defects which are fatal and those which can be overlooked in consideration of the counterbalancing good properties.

In Table 33 (pages 154-165) the net results of the preceding tests have been reduced to their simplest expression and a decision characterizing the clay as a whole has been reached. This may be of use as an example for others attempting a similar judgment on similar data.

TABLE No. 33.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
A		Oxidation.	Fairly rapid.	Favorable.	A good material. High warpage is its most serious fault.
	Water required for Plasticity: Moderate, 18%.	Color.	Moderate. Commercial between cones 04-1.	Color quality is good.	
		Hardness.	Changes rapidly between cones 06-04.	Steel hard or harder.	
	Shrinkage in Drying: Moderate, 5.50%.	Porosity.	Extinguishes very regularly at 3.05 per cone.	Moderate 12 to 5%.	
		Specific Gravity.	Indicates good structure up to cone 3.	Favorable.	
	Strength in Dried Condition: Moderate, 6.33 lbs.	Shrinkage.	Unusually smooth and regular.	Moderate to high, 10% to 12%.	
		Warpage.	Rapid, but regular rate.	High. 38% to 47%.	
		Overfire.	Stands several cones with no damage except color.		

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
B	Water required for Plasticity: Low.	Oxidation.	Fairly rapid.	Favorable.	An excellent material with an unusually favorable combination of properties.
		Color.	Slow, with commercial colors between cones 06-1.	Color quality is good.	
	Shrinkage in Drying: Low.	Hardness.	Changes very slowly and steadily.	Hard enough, but softer than steel.	
		Porosity.	Extinguishes very slowly. Rate 2.26% per cone.	Rather high. 17% to 7%.	
	Strength in Dried Condition: Moderate, 6.41 lbs.	Specific Gravity.	Indicates good structure up to cone 4.	Favorable.	
		Shrinkage.	Exceedingly slow, and gradual in rate of change.	Very low. 5 to 5.75% (total.)	
		Warpage.	Regular in rate.	Average in amount. 29% to 42%.	
		Overfire.	Stands a lot of heat without harm, except to color.	Favorable.	

TABLE No. 33—Continued.

Snmmary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
C		Oxidation.	Quite slow.	Unfavorable, but not severely so.	
		Color.	Moderate, but requires higher temperature than usual to get good shades. 02-3.	Color quality is good.	
	Water required for Plasticity: High, 22%.	Hardness.	Changes rather abruptly between 04-02.	Steel hard or harder.	A fair material, only. High warpage, high shrinkage, and quick vitrification make it a little difficult to handle.
	Shrinkage in Drying: Below average, 4.5%.	Porosity.	Extinguishes rapidly berween 06-04. Moderate rate thereafter. Rate per cone 4.17%.	Moderate, 14% to 4%	
		Specific Gravity.	Indicates good structure up to cone 3.	Favorable.	
	Strength in Dried Condition: Moderate, 5.95 lbs.	Shrinkage.	Rapid between 06-2. Very steady thereafter. Almost constant during period of useful colors.	High. 12% to 13.6%.	
		Warpage.	Regular in rate.	Rather high in amount.36-48%.	
		Overfire.	A reasonable range available.	Favorable.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
D	Water required for Plasticity: Rather high, 20%. Shrinkage in Drying: Quite low, 3.5%. Strength in Dried Condition: Low, 4.17 lbs.	Oxidation.	Exceedingly favorable.		A rather mediocre material. Properties are changing rapidly during the period of good colors, and overfire is easily reached. Raw properties not very good.
		Color.	Regular. Serviceable from 04-3.	Color quality is fair.	
		Hardness.	Changes are regular, reaching maximum at cone 1.	Hard enough. Harder than steel at finish.	
		Porosity.	Extinguishes rapidly 06-02. Moderate rate thereafter. Rate per cone 3.17%.	Moderate 13%-3%.	
		Specific Gravity.	Gentle changes. Best at cone 02. No point of marked failure.	Favorable.	
		Shrinkage.	Steady from 06-3. Volume changing during entire period of good colors.	Varies from 7% to 13%.	
		Warpage.	Steady in rate.	Average in amount 33%-42%.	
		Overfire.	Not a large margin available.		

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
E	Water required for Plasticity: Moderate, 19%. Shrinkage in Drying: High, 6%. Strength in Dried Condition: Good, 7.53 lbs.	Oxidation.	Very slow and difficult.	Unfavorable.	A good material for porous tiles, by working below cone 02 and slipping the product. Entirely unfit for any other kind of tile.
		Color.	Colors are unstable over whole burn.	Cannot be used without slipping.	
		Hardness.	Slow and gradual changes to cone 02.	Soft below cone 1. Hard above that.	
		Porosity.	Extinguishes with great rapidity from 02-3. Rate per cone 9.55%.	Unfavorable for hard tiles. Good if worked below 02.	
		Specific Gravity.	Fails rapidly from cone 04.	Unfavorable.	
		Shrinkage.	Begins at cone 02. Changes exceedingly rapid.	Unfavorable for hard tiles. Good if worked below cone 02.	
		Warpage.	Does not begin actively till cone 1 or above.	Very slight up to cone 01.	
		Overfire.	No margin at all above 02.	Unfavorable to last degree.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
F	Water required for Plasticity: Rather high, 20.65%. Shrinkage in Drying: Above the Average, 5.25%. Strength in Dried Condition: Moderate, 5 lbs.	Oxidation.	Rapid.	Favorable.	A mediocre material. Color is against it, and its good properties are not sufficiently marked to overbalance the color handicap.
		Color.	Rapid and unreliable. Best is only from cone 04-02.	Quality poor at all times.	
		Hardness.	Changes from soft to hard abruptly at 02.	Inferior.	
		Porosity.	Moderately rapid from 06-3.	High. 24%.	
		Specific Gravity.	Failure of body begins at cone 2.	Favorable.	
		Shrinkage.	Changes between 06-1 are moderate. Very slight thereafter.	Low. 8%.	
		Warpage.	Regular in rate.	Average in amount. 27%-42%.	
		Overfire.	Range ample for all purposes.	Favorable.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
G	Water required for Plasticity: Very low, indeed, 13.8%.	Oxidation.	Moderately rapid.	Satisfactory.	A good material. Worst fault is its warpage, which is about average.
		Color.	Moderate. Best Zone 04-1.	Quality of color, good.	
		Hardness.	Changes rapidly at cone 02.	Steel hard or near it.	
	Shrinkage in Drying: Very low, 20%.	Porosity.	Changes are very gradual. Rate per cone is 1.92%.	Rather high. 16%-10%.	
		Specific Gravity.	Rapid fall at cone 4.	Favorable.	
		Shrinkage.	Changes are gentle and uniform.	Low. 6%-8%.	
	Strength in Dried Condition: Very weak, 2.76 lbs.	Warpage.	Uniform and steady rate.	Average in amount 33%-42%.	
		Overfire.	Sufficient range.	Favorable.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
H	Water required for Plasticity: Quite high, 21%.	Oxidation.	Very slow.	Unfavorable.	A mediocre material if not actually undesirable. Properties changing rapidly during available color zone, and easily overfired. Low warpage is its best asset.
		Color.	Steady and gradual. Best 04 to 2.	Quality of color only fair.	
		Hardness.	Changes abruptly at cone 02.	Variable from soft to harder than steel.	
	Shrinkage in Drying: Very high, 7.25%.	Porosity.	Rapid changes between 02-3. Rate per cone 5.93%.	High. 26%-10%.	
		Specific Gravity.	Fails rapidly after cone 02.	Unfavorable.	
	Strength in Dried Condition: Very high, 11.5 lbs.	Shrinkage.	Moderate between 04-2. Bloats easily.	Varies from 7%-13%.	
		Warpage.	Slow to cone 04. Rapid thereafter.	Low, 24% or less.	
		Overfire.	Narrow range.	Unsatisfactory.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
L	Water required for Plasticity: Moderate, 17.21%.	Oxidation.	Moderately rapid.	Satisfactory.	If slipped and worked as a porous product, the mixture is not undesirable except on account of its easily exceeded overfire limits, and its warpage. The latter is known from the high warpage of its three ingredients.
		Color.	Changes between 06 and 1 are slow.	Quality is poor at all temperatures.	
		Hardness.	Changes slowly.	Steel hard or just below.	
	Shrinkage in Drying: High, 6%.	Porosity.	Changes very gradual. Rate per cone 1.48%.	High. 22%-16%.	
		Specific Gravity.	Body begins to fail rapidly at 02.	Not favorable.	
	Strength in Dried Condition: Not determined.	Shrinkage.	Changes steady and small.	Moderate 8%-10%.	
		Warpage.	Not measured.	Cannot be favorable.	
		Overfire.	Very narrow range. Easily spoiled.	Unfavorable.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
M	Water required for Plasticity: Low, 15.86%.	Oxidation.	Moderately rapid.	Satisfactory.	A desirable material. Will make a rather porous tile of moderate warpage.
		Color.	Changes slowly between 06-1.	Quality good.	
		Hardness.	Changes rapidly at cone 02-1.	Hard enough. Below steel.	
	Shrinkage in Drying: Low, 3.5%.	Porosity.	Changes rapidly between 02-3. Rate per cone 6.02.	High. 28%-22%.	
		Specific Gravity.	Begins to fail slowly at cone 1.	Favorable.	
	Strength in Dried Condition: Below Average, 4.79 lbs.	Shrinkage.	Changes slow and small.	Low. 5%-7%.	
		Warpage.	Regular.	Below average in amount, 21%-39%.	
		Overfire.	No overburning for several cones	Favorable.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
N	Water required for Plasticity: Rather low, 16.13%.	Oxidation.	Very slow.	Unsatisfactory.	If slipped and worked below cone 02, the properties of this clay are favorable for a porous tile. Absolutely unfit for any other.
		Color.	Changes very slow between 06-3.	Buff. Useless without slipping.	
		Hardness.	Changes vey slow.	Reaches steel hardness at 2.	
	Shrinkage in Drying: Moderate, 5%.	Porosity.	Changes very rapid between 02-3. Rate per cone 7.68%.	Very irregular, mostly high, 38%-6%.	
		Specific Gravity.	Begins to fail at 02 rapidly.	Not favorable.	
		Shrinkage.	Slow and gradual.	Low. 6%-10%.	
	Strength in Dried Condition: High, 9.05 lbs.	Warpage.	Very slight. Does not really begin till after 01.	Very low. 3%-6%.	
		Overfire.	No range at all, above 02.	Very unfavorable.	

TABLE No. 33—Concluded.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
O	Water required for Plasticity: Moderate, 18.74%.	Oxidation.	Moderately rapid.	Satisfactory.	A fair mater 1 only. Its porosity and shrinkage are both rather high, and its tendency to suffer from overfire is against it.
		Color.	Changes slowly 02-2.	Quality good.	
		Hardness.	Gentle and regular.	Steel hard.	
	Shrinkage in Drying: A little high, 5.50%.	Porosity.	Changes steady and not rapid. Rate per cone 3.36%.	Rather high, 20%-12%.	
		Specific Gravity.	Remarkably uniform. No failure at cone 5.	Very favorable.	
		Shrinkage.	Rapid from cone 04 to 1.	Moderate to high. 10%-14%.	
	Strength in Dried Condition: Not determined.	Warpage.	Not determined.		
		Overfire	Very little margin, a serious de-defect.	Unfavorable.	

CHAPTER IV.

THE PREPARATION OF ROOFING TILE CLAYS.

The processes to be considered in this chapter include all that deal with the winning of the clay, its transportation to the plant, its grinding, the production and increase of plasticity, its aging and its chemical treatment to avoid efflorescence.

In discussing these topics it has not been the intention to write a text book on all known methods of clay preparation, which would carry the book much beyond the proper limits, but to state somewhat fully how the roofing tile manufacturers are now actually solving their several problems, in the belief that a discussion of these facts may be of more use to roofing tile makers, present and prospective, than the more general treatment.

VARIETIES OF CLAYS USED.

The discussions of the preceding chapter on the clays used in roofing tile manufacture in this country have made clear their physical and chemical properties, and their origin, or geological occurrence, has been made known. In connection with the preparation of clays, it is again desirable to consider their varieties.

If the occurrence of the clays now actually in use in American roofing tile plants be tabulated, we will find as follows:

(1) Glacial clays, containing a considerable quantity of stone and lime	1 plant
(2) Alluvial or river flood-plain and lake-bottom clays, containing sandy streaks, but practically no stones or coarse impurities	3 plants
(3) Shale beds, accessible for superficial workings	9 plants
(4) Shale beds, under heavy cover, and requiring mining operations	1 plant
	14 plants

So far as winning is concerned the first two groups may be lumped together, as the modes of operation are in general the same. The superficial shale beds make a group by themselves, differing from the first two chiefly in the difference in hardness of the clay and the use of explosives to loosen it. A third mode of winning is represented in the single case of mining an underground vein.

WINNING ROOFING TILE CLAYS.

By winning is meant the operation or work performed in loosening a mineral from its natural bed and loading it ready for removal to its next destination. In many places the transportation and delivery of the material to its next destination are considered as a part of the definition of winning, but it seems better in the interest of clearness to keep these matters separated.

The methods employed are many, depending upon the nature of the material, its position with regard to the surface, its hardness, the quantity required, etc., etc. They may be roughly classified, so far as the present purpose is concerned, as open pits, quarries and mines.

OPEN PIT WORKINGS.

As a general thing, open pit workings are confined to soft clays, such as the glacial and alluvial types, which do not require blasting to loosen them, and which have not the necessary hardness and rocky structure to make either mining or quarrying possible.

Open pit workings take on very different proportions and characters in different parts of the world, according to the peculiarities of the clay beds, the customs of the country, the kind of labor, the climatic conditions, etc. In rare cases they are of enormous extent and great depth, but in the ordinary or typical cases they are shallow excavations, from two or three feet to fifteen or twenty. Soft clays are seldom worked with very deep pits, because of the danger of their caving during rains. It is practicable in some few cases where soft clay of one kind occurs in a very thick bed to make a deep excavation with banks sloping on the angle of stability of the clay when wet. But where the clay sought at deep levels is desired, and a heavy stripping is to be removed, then the open pit is no longer an economical method.

An open pit working may, then, be understood to be any kind of a cut in the surface from which clays can be won, provided that it involves no blasting, or but very little, to make the clay workable by the ordinary dirt-moving tools and apparatus. It may be a straight cut through a plain or ridge, or a crescent-shaped side-hill cut, or a shallow superficial pit of great area, or a steep-sided, bowl-shaped cavity, or even a vertical-walled shaft of large cross-section—all are entitled to the name of open-pit workings.

The open pit is the most difficult form of all clay deposits to operate, owing to the fact that the deposit, in the nature of the case, must be subjected in all stages of working to the influences of daily weather changes and frequent storms. Rains not only usually drive the laborers from the field, but, if of any duration, so wet the clay that it becomes too soft or sticky to work it when delivered to the factory. The above conditions are to be expected occasionally during the summer months,

but from about November to April in states north of the fortieth parallel of latitude it is usually impossible to operate except at a prohibitive cost. This entails that the manufacturer shall provide storage sheds, which he is obliged to fill during the summer months. These must be of such a capacity as will tide his work through the months in which he is unable to gather clay from the field, or else it involves the stopping of the plant for from a quarter to one-half of the time.

Winning clay from open pits may be discussed under two headings, viz: (1) The actual operations of the clay digging or excavation, and (2) the subsidiary operations of draining the works, timbering, track laying, protecting from weather, etc.

The excavation is accomplished by pick and shovel work, by plow and scraper work, by clay-gathering machines, and by steam shovel work.

Pick and Shovel Work.—This is the most elementary method in use in clay works among the civilized races. It is the most expensive method of all in labor, and the least expensive in equipment. The tools are the pick and shovel. It is in use in surprisingly many clay works today, and it is not uncommon to see clay handled more than once by this method before it reaches the preparing machinery. The costliness of the method depends very largely on the following two factors:

1. The hardness of the clay, whether requiring much picking or not. Some require no picking. Others must all be picked before any shoveling can be done.
2. The nature of the pit-bed as a shoveling-floor, whether smooth or rough, and also the nature of the material to be shoveled, whether fine and sandy or coarse and lumpy, or flat and plate-like.

In general, the use of this method is caused by lack of capital, but there are cases where the clays contain impurities that can be rejected by hand-digging and not by other methods, or when different layers of clay must be kept carefully separated, as they are reached successively in the pit. In such cases, pick and shovel methods cannot be replaced by any other.

Spading.—A modification of ordinary pick and shovel work, known as spading, is used in some clays very successfully. It requires a clay of wet, cheese-like consistency, comparatively free from bowlders or foreign matter which would stop the cut of the spade. Such clays can often be worked with vertical walls and stand for long periods without caving. This method of working is not uncommon among the plastic clay beds of New Jersey and the Atlantic coastal plain, but among the older and consolidated clays of the Mississippi Valley it is not very commonly used. In only two instances, among the present roofing

tile plants of the country, is this method used: viz., at the Detroit Roofing Tile Company, Detroit, Michigan, and the Ludowici Celadon Company's plant at Ludowici, Georgia. The former clay bed is of glacial origin, and has the peculiar, tough, cheese-like nature which makes spading the logical mode of extraction. (See Figure 56.) One of the best examples seen of the spading system was at the Ludowici, Georgia, plant of the Ludowici-Celadon Roofing Tile Company.

Fig. 42—Clay Pit and Transportation System at Ludowici, Georgia.

The clay in this pit is of a very soft, fine-grained, plastic nature, having a depth of about six feet, and at the bottom resting on a bed of fine white sand. Quoting from Veatch, "The Clay Deposits of Georgia":

"The clay used is located near the factory on Jones Creek, a small tributary of the Altamaha river. The deposit is of Pleistocene age and is probably the equivalent of the second bottom or Columbia deposits of the Chattahoochee, Ocmulgee and Savannah rivers, and was deposited during a high stage of water in the Altamaha river. The deposit is about six miles distant from the river, but is at the present time occasionally flooded by back-water from the Altamaha.

"The clay is four to seven feet in thickness, has practically no overburden and is underlain by a white water-bearing sand. It is yellowish, red, and bluish in color; a mixture has a yellow color, is very fine-grained, stiff and plastic. It is free from pebbles, coarse sand or coarse rock fragments. The clay is noticeably bluer, stiffer and more plastic around the roots of old stumps, a change evidently effected by organic acids from the wood. The deposit is mined in small separate pits, with pick

and shovel; water accumulates rapidly in the pits and drainage facilities are poor, and in winning the clay a clay partition is left between the pits, to prevent the water which accumulates in the abandoned pits from flowing into those which are being worked. The clay is hauled to the plant, which is about one-half mile distant, in cars pulled by mules.

Unless the method of winning clay by shovel is properly carried on, very annoying results may be expected. For instance, if a pit is not uniform from top to bottom, i. e., there are certain layers or strata varying in physical properties from the bulk of the deposit, and is taken off layer by layer, there will be a very variable product in the finished ware.

Should this same pit be worked in benches, loading into each car a certain number of spadings each time from the various benches, a uniform product will be the result.

While it is possible to get a very uniform mixture of material by the shovel method, this point is most often neglected and little attention is given to the order in which the strata are loaded.

The Plow and Scraper Method.—This simple and everywhere familiar mode of excavating and moving earth is available as a mode of winning soft clays. The limit of hardness which a clay may have and still be amenable to plowing and scraping is usually known as "hard-pan." Hard-pan is commonly bowlder clay, so compact as to be almost impossible to plow and so full of stones as to keep a plow jumping out of the furrow or stalling. Shales cannot be plowed or scraped, except on their weathered surface. When the full hardness of even a soft shale is reached, the method becomes an ineffective one and hard shales cannot be worked in this manner at all.

The plow and scraper method is used more as a means of stripping earth or clays from the surface of the desired stratum than it is for the winning of the stratum itself. The removal of from a foot or two up to eight or ten feet of undesirable earth and clay from a good stratum is within the limits of ordinary commercial conditions, but for regular strippings of more than ten feet in thickness, the use of a cheaper system than the plow and scraper becomes necessary, and hydraulic jets to wash the clay away or steam shovels or mechanical excavators are used.

It will be observed that this system is finding its chief use as an auxiliary to some other mode of winning. The materials stripped are usually *spoil* which goes over the dump bank or is used for grading purposes. But, if the materials removed are in themselves fit for use, their winning can be accomplished at a comparatively low cost. In the matter of securing a homogeneous daily output from a bank composed of strata of different properties, this can be accomplished, as in hand work, but only by the daily exercise of care and pains. In general, men dislike to plow up hill or down hill, and in a bank with

horizontal beds the strong tendency of the men would be to take it off layer by layer, in the very way that makes the most serious trouble in the factory. By working the bank on an incline, so as to cut all strata at an oblique angle, or by taking it out in benches and mixing the products of the benches in the ratios of their occurrence, an output may be obtained of quite uniform character from a bank of variable composition. The extra supervision to secure this result and the little daily losses of time in waiting for the different loaders to deliver their quota in turn, will surely make the method quite a little more costly than that of straight stripping work.

One of the troubles incident to this mode of working a plastic clay pit is in the matter of wet clay after a rain. The use of horses and plows, etc., makes the pit muddy at once and the clay is sure to be so sticky as not to be fit for immediate use or for storage. A lump of plastic mud will stay wet a long time if buried under a pile of similar material. This difficulty constitutes a very real and important restriction to the use of this plan for storing clay in sheds for winter use.

The Clay Harvesting or Gathering System.—This plan is devised to meet the objections raised against the plow and scraper system in the preceding paragraph and is used by those of the industry who are not only obliged to win a supply of clay for the daily consumption of the plant, but in the summer months must provide a supply sufficient to run their plants throughout the winter. This means that a large amount of material must be handled within a short period of time.

Two plants, those of the Ludowici-Celadon Company at Chicago Heights, Illinois, and the National Roofing Tile Company, at Lima, Ohio, are making use of a very excellent machine for the purpose, the proprietary name of which is "The Quincy Clay Gatherer." It is made by the Central Iron Works, at Quincy, Illinois.

This machine consists principally of an open-topped drum or barrel, supported between two wheels, which in turn cause a set of scrapers to revolve around the drum. These scrapers scoop up the previously loosened clay, and carry it on their trip around, until upon reaching the opening at the top of the drum the clay drops from the scrapers into it.

A drive of twenty or thirty yards is sufficient to fill the drum, which holds approximately one cubic yard. The scrapers are then raised and the load is hauled off to the storage shed or grinding room, where the drum by means of a trip or latch is caused to revolve with the wheels. As soon as the drum has made about one-quarter of a revolution, the clay begins to empty out of the open top and by the time the complete revolution has been made, the entire load has been discharged.

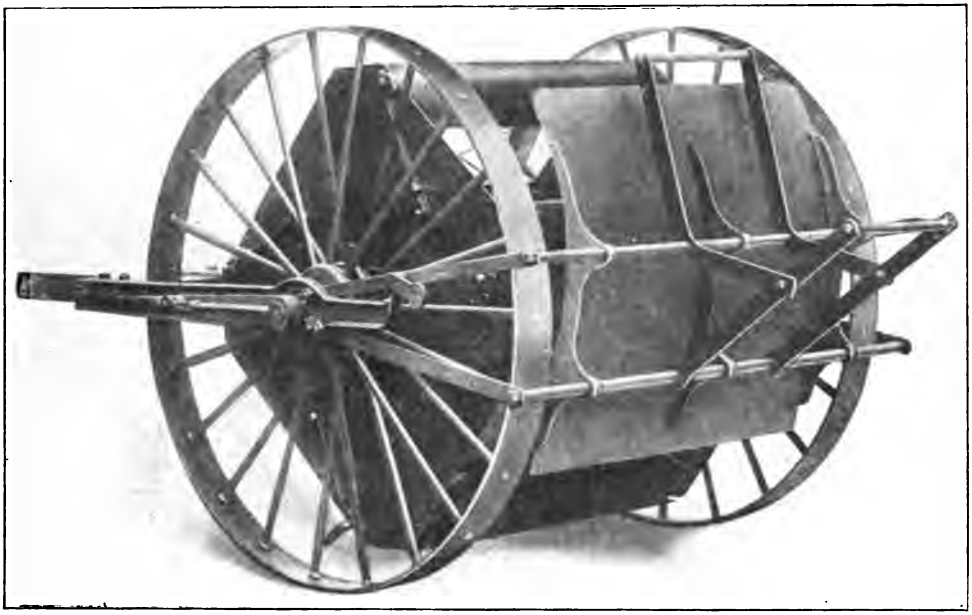


Fig. 43—Quincy Clay Gatherer.

This method of winning clays is to be commended, owing to the fact that the layer of clay cut off from the surface of the ground is thin, only an inch or two, and even if the field is wet, after rains, the use of a drag or harrow to cut up the surface and air it, and the removal of the aired clumps of clay in a series of very thin cuts, enables clay to be gathered with but little interruption from summer showers, and still procured in excellent condition for storing. The method excels that of the plow and scraper only int his point.

It is an excellent mode, also, of obtaining a uniform mixture or average, where the clay formation occurs in parallel strata or beds, if it is properly worked, but requires the same careful supervision before described to see that all levels of the pit are being worked simultaneously.

The gathering, to be properly done, requires the proper opening of the field, or pit. This is done by working the field on an inclined plane, having a depth equal to that of clay stratum to be worked. To properly gather the load of clay, the scraper is started at the bottom of the pit, driving either straight or diagonally to the top of the pit, then turning round and driving down the low sloping side again. A load so gathered represents an accurate mixture of the deposit over its entire cross section.

The sampling does not cease with the loading of the material, but is again perfected at the unloading point. As described before, the

load is not dumped at a single point, but is distributed over the storage shed floor for a distance of ten or fifteen feet.

It will be understood, though, that the advantage of the use of this clay gathering device is restricted. It can only produce a strict average of the clay, where the latter occurs in parallel strata. In a bed of folded, or unconformable, or irregularly mixed clays, such as are often found in the more recent clays, this system would lose much of its efficiency as an averaging device, though it could scarcely be improved upon by anything else except careful hand winning. It might possibly be used on very soft shales, provided the bank could be opened over a area large enough to properly carry on the work.

The use of the clay gatherer is much more applicable to the glacial and alluvial clays, whose bedding is always horizontal. In working these soft clays it is necessary to precede the gatherers by about half a day's work with a tool known as a drag, or plow, which loosens the clay to a depth of about two inches.

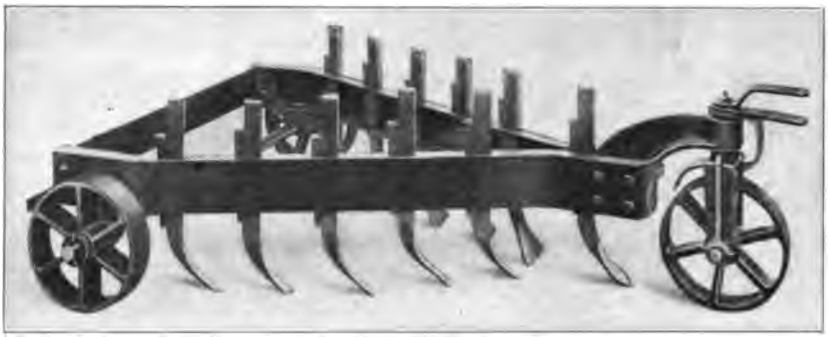


Fig. 44—Quincy Clay Plow.

This machine not only loosens the clay, but puts it into a condition such that it will become more or less dry by the time the scrapers reach it.

It will be found next to impossible to work wet or sticky clay by the clay-gatherer. The clay will pack in the drum, and give much trouble in dumping.

The drag, or plow, shown in Figure 44, consists of a triangular wooden frame about five feet on a side, supported or carried at the three corners by small wheels. Distributed along the sides are small plows, or teeth, such as are to be seen on the ordinary farm cultivators. These teeth extend about two inches below the bottom of the wheels that carry the frame. Three horses are required for the plow, which cuts or loosens a path of clay about five feet wide. The action of the plow is similar to a harrow, except that its plows have a little better cutting power than a harrow.

Fig. 45—Quincy Plow in Action at Pit of Ludowici-Celadon Co., Chicago Heights, Ill.

Fig. 46—Quincy Clay Gatherer at Work in Pit of Ludowici-Celadon Co., Chicago Heights, Ill.

The Steam Shovel.—Another method of winning clays very widely used in both soft and hard clays is the steam shovel. The general nature of this machine is so well known that it will not be necessary to describe it here. It is a notable fact that not in a single instance in 1908 was the steam shovel being used to win clays for the roofing tile industry.

This state of affairs can easily be explained when we consider that the amount of raw material consumed by a roofing tile plant is relatively small when compared with the brick or sewer-pipe industries. For instance, if a roofing tile plant was producing one hundred squares per day, this would require in the neighborhood of fifty to sixty tons of material. Should this same amount of material be made into building bricks it would produce approximately 12,000 to 15,000 of standard size and much fewer of paving brick. This would be considered a very small plant, and for the tonnage required no one would think of installing a steam shovel. The investment and the expense of maintaining and operating the shovel would be entirely out of proportion to its capacity. On the other hand, a roofing tile plant of a capacity of 100 squares a day would be considered of very fair size. It would not be economical to use a steam shovel equipment for a roofing tile plant unless the plant were a very large one.

WINNING OF SHALES.

As stated before, of the fourteen plants visited, ten are using shales, nine using open pits or quarries and one drifting or mining into the hillside.

Shales differ from glacial and alluvial clays in the matter of being hardened to a point where they can no longer be loosened by the spade or shovel, and generally not by a pick with any economy. The hardened clays or shales almost always require blasting to break or loosen them from their present mass, and even when thrown in a pile of loose material by a blast, they generally come out in such heavy, coarse lumps that a further recourse to the pick, sledge and bar are required to break them down into sizes accepted by the crushing machinery. Often auxiliary shots, or "pop shots," are employed to break the bigger pieces after a big blast has thrown down the face of a shale pit.

Before studying the methods of quarrying shale, it would seem best to first fix in mind what conditions are to be found at the average shale bank in use.

In the majority of cases the bed of shale will be attacked at some point above surface grade—that is, at a higher level than the plant or surrounding territory. Of course, shales may occur at any level with regard to that of the plant, but the difficulties of operating any clay pit below grade are so much greater than one with free drainage that clay

workers generally hunt for an exposure of the proper material at the proper elevation instead of attempting to work one at a level too low to permit natural drainage. Of course, in some localities, where shales are scarce, the deposit is worked where it can be found, and a low level is accepted as one of the natural obstacles to be met and overcome.

Fig. 47—Shale Bank of the United States Roofing Tile Co., Parkersburg, West Virginia.

Shales are usually well stratified, but in some cases, as at the bank of the United States Roofing Tile Company, at Parkersburg, W. Va., the stratification of the shale is very slight or has become partially obliterated.

At the plant of the Huntington Roofing Tile Company, Huntington, W. Va., are to be found two shale banks in use. The lower, or No. 1 bank, (Figure 48) contains an extremely fine grained, well stratified shale, quite

soft and easily dislodged. Their No. 2 bank is made up of a very sandy shale, well stratified and very hard, breaking out or blasting in very large blocks, as seen in Figure No. 49. On the left hand side of the same figure can be seen a large pile of slaked or weathered shale. This company was in 1908 the only roofing tile concern in the United States that was weathering its raw shale.

During the summer months of each year large amounts of the shale are blasted loose, and then wheeled out and heaped up in a windrow or long pile three or four feet deep, and allowed to remain until the following year. This allows the natural agencies to break down the massive blocks of hard material, which would otherwise have to be done by hand or machinery. In this particular case the clay is improved in another way, viz., the soluble salts of lime and magnesium that are present in the parent ledge are leached out and carried away by the rains, leaving the shale much improved in quality.

Stripping.—By observing the pictures of the various shale banks shown in this report, it will be noticed that the overburden ranges in thickness from a foot or so, up to many feet. The removal of this overburden, if large, becomes a serious source of expense, and a problem in the management of the quarry. In most cases, the stripping is done by plow and scraper. If the road to the wasting point is short, the small dump-scraper is used, but if the distance is over 100 feet, the wheeled scraper is the better and more economical machine to use, on account of carrying much larger loads.

At none of the roofing tile plants has the use of hydraulic jets been taken up, in removing the stripping or overburden. What was said of the use of the steam shovel as a mode of winning for roofing tile plants applies to the use of the hydraulic method of stripping,.in some degree, i. e., the amount of material to be moved will not ordinarily justify its use. This does not apply with equal force, however, for while a steam shovel of the smallest size would be much too large for an ordinary roofing tile plant, it is possible to make hydraulic installations on almost any desired scale.

The method consists in the application of streams or jets of water from a hose pipe, under high pressure, usually 100 pounds per square inch at the nozzle, against the face of the soft clay. The water will burrow its way into the clay, and wash it into a slime or thin fluid, which will flow off through runways. The labor of this system is at a minimum—the nozzle-man is the only one employed for hours at a time. But the system requires the use of great amounts of water and the service of an engineer to provide it, and also requires frequent changes in the pipe-lines, the runways, the receiving ponds or fields on which the slime is distributed, etc.

Fig. 48—Clay Pit No. 1. Huntington Roofing Tile Co., Huntington, W. Va

Fig. 49—Clay Pit No. 2. Huntington Roofing Tile Co., Huntington, W. Va.

When all such costs are included, there is no question but that this mode of moving sand, gravel, clay, etc., is still far below any other method. It requires, however, conditions that are not always found, viz., adequate water supply, and a place to distribute the materials used —the latter is often more serious than the first. The method may be said, therefore, not to be susceptible to general adoption, though exceedingly cheap where the conditions favor its use.

At the Parkersburg plant the stripping is done by pick and shovel. The bank is on the side of a very steep hill, so that it is only necessary to loosen the overburden and give it a start with a shovel and it falls to the bottom of the pit, where it is loaded into dump-cars and sent down the incline to be used as grading material in the low lands below.

In the ordinary shale bank, the usual method of procedure is to first uncover or strip the surface of the shale over an area which will furnish a year's run. This is mostly done, as stated before, by teams and scrapers. In the work of developing the bank at first, this preliminary stripping is often done by pick and shovel. This is continued until a working-face has been exposed, that is, an exposure of the shale for some distance laterally along the out-crop, and having a vertical section equal to the depth of the stratum, or if this be too great, so much of it as may be desirable to work. There is naturally a good deal of extra stripping to be done in opening up the ordinary shale pit, before the conditions of quarrying become normal. The soft or weathered edge of the shale is usually to be removed, and an excess of surface-clay or stripping has to be taken off. Gradually, as the workings progress back into the hill, the face of the stratum exposed becomes normal, i. e., the proportion of surface-clay, weathered shale, and hard unaltered shale becomes more nearly constant.

The height of a shale stratum which can conveniently be worked in one bench is not over twenty or twenty-five feet. The disadvantages of too high a face are great—it is dangerous, when caving, and inconvenient to get up and down, in loosening hanging pieces, etc. A thirty-foot bank is generally better worked in two fifteen-foot benches, rather than in one of thirty feet.

Quarrying.—The actual operation of quarrying differs from hand-digging in the use of explosives. Everything else is common to the two modes of working. Or, rather, after a shale has been blasted, its loading is practically the same as hand digging, though the proportion of use of bar, sledge, and pick is greatly increased and the use of the shovel is somewhat reduced. In many cases men will lift much of the shale in large lumps by hand instead of by shovel.

Blasting.—The work of disrupting rocks or earth by explosives may be divided into three parts, viz.: 1st, drilling or preparing the hole for the reception of the explosive, 2nd, the loading, or preparing the explosive charge, and equipping it with ignition or firing mechanism,

and 3rd, "shooting" or exploding the charge. For drilling, and in fact throughout this work, two men usually work together as a crew.

Drilling.—Drilling holes in rocks at its best is a specialized business, with large mechanical equipment and room for the exercise of much skill. In general, however, drilling is done in four ways: 1st, by hand; 2nd, by augers turned by hand power, with or without a mechanical feeding appliance; 3rd, rotary power-drills; 4th, percussion power-drills. The choice of a method for any given case depends on the amount of drilling to be done, the hardness of the rocks, the depth and diameter of the holes, the necessity or advantage of speed in drilling, the wetness of the strata, etc. In general, clay and shale is prepared for blasting by the first two methods, especially in the roofing tile business, for the amount of clay needed would make the installation of a modern drilling plant an absurd extravagance.

Hand Drilling.—The tools required for this work are: a five or six-pound sledge-hammer, usually three drills or "spuds," varying in length from three or four feet in the shortest, up to ten or twelve feet in the longest. It is necessary to have these various lengths to suit the convenience of the men as the hole deepens. The drills are of tool-steel, ⅞-inch to 1¼-inches in diameter, drawn out at the lower end into a fan-shaped bit or cutting-point. A bucket of water, a dipper, a brush or "swab" and a scraper for cleaning out are also needed. The drillers most often provide their own swab by cutting a young sapling (of hickory preferably) an inch or so in diameter and about ten feet long. Then by pounding or mashing the thick end of it with the sledge, they fray it out for a length of six or eight inches.

The actual process of drilling a hole for a blast is a process similar in nature in all materials, but varying greatly in difficulty or the amount of energy required. In the softest clays which need the use of explosives, the drill can be driven into the clay by merely lifting and dropping it, or "churn-drilling." In fact most shale clays can be churn-drilled.

When the shale is quite hard, the drill requires the use of more power. In drilling a vertical hole, one man takes the sledge, the other the shortest drill, which he holds plumb at the point previously selected. The man with the sledge, called the striker, proceeds to strike the drill with quick, sharp blows, while at the same time the driller between each blow of the sledge raises the drill a short distance and during the same interval twists the drill through an angle of from 30 to 40°. Each four or six blows therefore cuts the bottom of the hole over its entire area, creating numerous small chips of the loosened rock.

They proceed thus until they have drilled down through from several inches to a foot or so of the shale. A dipper of water is now poured down the hole and the brush end of the swab is inserted, and after a short churning up and down is withdrawn laden with the newly made mud. On withdrawing, the swab is given a sharp blow or rap

over a block of wood or a stone, thus freeing it of the accumulations; possibly a little more water is added, and the work repeated until all the mud made from the drillings has been withdrawn. The drill and sledge are now brought into play again. Thus the work proceeds, until the desired depth is reached, usually not exceeding ten or twelve feet. The hole is now dried and cleaned out as carefully as possible, by pouring down a handful or so of dry clay at a time and withdrawing it in the spoon or scraper. In wet clays, or shales permeated with water-bearing seams, this drying of the hole is very difficult to do, and recourse is had to a cartridge of oiled or soaped paper, which will slip down the hole quickly and permit a shot to be gotten off before the water soaks through the paper.

Auger Drilling.—This method is applicable to clays and shales of all degrees of hardness. It is limited to rocks of about that grade, such as coal, gypsum, talc and soft limestones, and is inapplicable to really hard rocks like sandstones, granites, etc.

The simplest form of this work is a double brace, or handle devised for twisting the auger around an imaginary center, using both arms to maintain the motion and the chest to supply the pressure of the drill against the rock. This is applicable to soft clays and only the softest shales.

The common forms are frames, arranged to fasten upright or inclined between the floor of the quarry or mine and some point above it, in the face of the rock, or the roof of the mine. This frame is braced in position by screws and guys. The auger is mounted on the end of a long screw or threaded steel bar, which is passed through a nut fastened in the frame described above. By turning the screw, it feeds itself through the nut at the rate prescribed by the pitch of its threads, usually one-eight of an inch per revolution. The turning is done directly by a crank or handle on the end of the screw, or by the intervention of gears, with two or three different rates of motion, if the rock to be drilled is fairly hard. The power is supplied by the driller himself.

These machines are of wonderful service in mines, where the roof and floor offer facilities for fixing them in position readily. They will make holes at almost any angle, but most easily when nearly horizontal. They are used, but less readily, along the foot of a shale bank, in an inclined position, and for making horizontal holes or holes inclining downward. They are practically useless for making vertical holes, in open workings. A man will make in a six foot hole, 1¾ inches or 2 inches in diameter, in ordinary shale in from twenty to thirty minutes, and often much quicker.

Rotary Power Drills and Percussion Power Drills.—These may be left out of consideration, as they are only suited to very large quarries or to rocks of greater hardness than shale clays. Some few brick works

in the country are large enough to make their use economical, but certainly no roofing tile plant could do so.

Springing the Hole.—This practice is only used in rather soft rocks or such as are penetrated with many fissures for the escape of the explosion gases. It is done by firing a small piece of dynamite—usually a section of a stick an inch long is enough—at the bottom of the hole. It does two things. First—it dries out the hole by the hot gases liberated there. Second—it makes a cavity usually pear shaped or spherical in shape, which acts as a receptacle for the explosive. It thus makes it possible to get in a much larger quantity of explosive and also to concentrate it in a relatively large mass, instead of spreading it up and down a large vertical range.

Choice of Explosive.—There are two classes available—the slow combustion powders and the instantaneous or chemical explosives. The powders burn very rapidly it is true, but nevertheless they generate their explosion by ordinary combustion. The chemical explosives generate their explosion by molecular decomposition, not like combustion at all, though it is accompanied by heat. The difference between the two is very great. The powder is slow, relatively, and weak in its effects. The chemical explosives, represented by nitroglycerine and dynamite, fulminates of silver and mercury, etc., work with much greater speed and much sharper or concentrated effect. This difference decides the use of the material for its proper place. Soft, loose, uncompacted, or "leaky" rocks, like shales, need powder. The effect of dynamite is dissipated too much. But hard, dense and "tight" rocks need dynamite. Either kind will of course do something in any place where used, but their most efficacious use is as above set forth. Many shale drillers use a mixed charge, partly dynamite to "start" the explosion, and the balance black powder to "follow it up," these terms referring to the difference in rate of action. The economy of thus mixing charges is open to question.

Altogether, the technique of blasting, though simple, is nevertheless considerable, and there is room for the acquirement of great personal skill in handling the explosives judiciously. A good blaster will do three or four times as much work with a box of explosive as an inexpert one.

Loading.—The next step is to get the charge properly into place in the hole. The desired quantity, usually such as will about half fill the hole, is dropped in, a water-proof fuse tape being first let down the hole until it nearly touches the bottom, then is cut off from the reel or main supply about a foot above the top of the hole. Then fine dry dirt or clay is put in on top of the explosive and by means of the tamper or reverse end of the drill, is carefully compacted. More is added and tamped at short intervals, damp clay being used after the first addition. When the hole is entirely filled, the fuse is lighted and the men re-

float to a safe distance. Usually a minute or two elapses before the explosion. Where dynamite is used extensively, an electric sparking apparatus for igniting a charge is used very commonly. It has the advantage of not being subject to dampness, and also of making it possible to ignite any number of charges simultaneously. For small plants, it is not needed, though used by some on account of the somewhat less danger of premature or delayed blasts. In most cases it will be found that the bottom of the bank has been blown out, and the mass above has either tumbled down at the foot in a rough pile, or is loosely hanging, ready to fall with a little assistance from the bar or pick.

In cases where the shale is hard it will be found necessary to sledge apart or break up the large blocks before loading into wagons or cars.

In favorable cases it is not unusual to dislodge from fifty to several hundred tons at a single shot, depending on the size of the bank and many similar conditions.

In Figure No. 48 can be seen the effect of a newly-made blast. All of the loose material behind the wagon was brought down by a single shot. The tamping rods, drills, and other tools for the work, can be seen on the bank above the fall of shale.

It will be readily understood that the work of shooting out the shale for a roofing tile plant each day is only a matter of one or two well-placed shots.

It is not unusual for two, three, or even five holes to be drilled and fired at the same time, thus providing a week's supply of material at a single operation.

The Placing of Shots.—In this subject lies the most of the skill of the quarryman, and one man exceeds another in the judgment he displays in placing shots where they will do the most execution. The art cannot be learned except by practice and experience, but many who have practice and experience in plenty never make expert blasters. The quarry boss usually supervises this himself, and aims to have each shot so placed that, when fired, it will expose a new point of advantageous attack. The nature of the rock, its seams and openness, its cleavages or lines of break, its tendency to hang or merely loosen up without lifting out of its bed, its rate of use at the plant, the extent to which it hurts it to be wet or caught by rains after blasting—all these and many more things have to be considered in laying out the work of a quarry. A good quarry boss can tell what his plan of campaign is for days ahead of his work, and has provided in this plan for the contingencies of stormy weather, shortage of men, etc.

Clay banks are generally worked in a long line, approximately straight, or on a gentle curve, or else they are worked with two faces, one at right angles to the other. Some, of course, are erratic in shape, on account of irregularities of deposit or local obstacles.

MINING.

The third method which was found in use in the winning of roofing tile clays was mining. The formation mined was a shale of the Coal-Measure period, at the plant of the Murray Roofing Tile Company of Cloverport, Kentucky. The shale bed here is capped with a ledge of limestone, making a good safe roof whenever the cover was deep, but around the out-crop the fissures of the limestone had been widened by the percolation of rain water until the stratum was cut up into blocks. These blocks, if undermined, completely or largely, then became very difficult to hold up, and hence dangerous.

Fig. 50—Entrance to Shale Mine, Murray Roofing Tile Co., Cloverport, Kentucky.

The shale stratum mined was about twelve or fifteen feet in thickness. The mine was situated closely in rear of the plant, and the tram car haulage from the mine led directly into the stock-room of the factory.

The mining of a stratum of moderate thickness, five to ten feet, is simply a modification of quarrying. The modes of blasting, loosening the material, sorting and loading it for transportation are all the same, or differ only in minor details from ordinary quarrying outdoors. But there is introduced an entirely new set of factors, viz., the support of the strata overhead to prevent caving in, and the conducting of ventilating currents into the mine and out of it, to make the air pure and healthful for man and beast. The problems of haulage and drainage are not much different from the same factors outside.

The timbering or supporting of the roof or hanging wall, is a heavy factor of expense in nearly all mining. This factor varies with the thickness of the stratum mined, for the longer the timbers must be to reach from floor to roof of the chamber, the heavier and more expensive they are.

The ventilating of a mine also calls for the use of fuel, either burned directly in the old-fashioned ventilating furnace, or indirectly in steam engines or gas engines, by which fans are driven, forcing pure air in or sucking vitiated air out. The ventilation also requires the driving of special passages, break-throughs, over-casts, and the erection of doors, stoppings, brattices, etc., for direction of the air currents past the old and abandoned workings, and into the new workings where they are needed. To properly ventilate a large mine is a problem requiring high-grade skill and experience.

It is obvious that to work in cramped quarters, in artificial light, to provide an artificial air supply, to provide timbers for preventing the beginning of caving in, in addition to the normal expenses of quarrying, draining, loading and handling, is bound to make mining an expensive form of winning. It cannot be otherwise. Its average cost per ton may be said to run from about twice to three times what the quarrying of the same material in the open would be.

There are, however, some advantages to offset the extra cost. The ability to work the mine all the year around and deliver a constant supply of material in the same condition as to dryness, in all kinds of weather, is a matter of the highest importance to a clay plant. The use of the mining method of winning ordinarily does away with the need of a storage shed for housing a winter's supply, and for the investment of large sums of money in clay which has to be stored months before it can be used. It also provides, ordinarily, a more regular daily operation of the plant with far less variation from day to day than when clay direct from an open pit is used, since it does away with wet and muddy material and delivers its product in the same state all the time. More regular operation means a larger output with the same force of men. So that, while mined shale is more costly than quarried shale, it does not necessarily follow that the output of the plant is costing more in the long run.

Mining shale is more difficult in general than mining fire clay, or coal, or other formations, on account of the thickness of the strata and the extraordinary length of timbers required. For this reason, a shale mine is very rare, and represents conditions seldom met, while the mining of fire clays and kaolins is quite the usual or common method of working these clays.

Draining Clay Pits.—Clay pits, whether open or under ground, and in soft or hard clays, very commonly are so situated as not to be self-draining. On side-hill excavations, the problem of draining is usually

merely a matter of a little ditching. But, on level grounds, where clay pits are really pits in the true sense of the word, or in mines where the formation dips away from the opening, the problem of keeping the workings dry is a factor to be seriously considered.

There are a considerable variety of means available. The following were observed in actual use in clay pits of the roofing tile companies of this country.

1st. Centrifugal Pumps.—This style of pump is capable of handling the mud and gravel that is sucked in with the water, without the cutting and clogging effects that occur with a piston-actuated pump.

The Ludowici-Celadon Company's Plant at Chicago Heights, Ill., has in use a motor-driven centrifugal pump that throws, when working at full speed, a solid six inch stream of water. This very large and powerful installation is made necessary on account of the large size of their clay-pit, some six or eight acres; it clears it in a reasonably short

Fig. 51—Motor-Driven Centrifugal Pump, in Use at Clay Pit of Ludowici-Celadon Co., Chicago Heights, Ill.

time. The above company is using the same kind of pump at their "Dixie" plant at Ludowici, Ga. For large plants, or for large clay pits, or for small but very wet clay pits, the centrifugal pump is the most

efficient mode of draining. Its ability to handle anything that will flow through a pipe is a great point in its favor. It requires an expensive installation.

2nd. Steam Ejector.—At another plant, where the pit i very much smaller and the water to be moved correspondingly less, a steam ejector is used to drain the clay field. The ejector, while very cheap in first cost, is of low capacity, and at the same time is a most expensive and inefficient way to use steam. Supplying it with steam is usually inconvenient and expensive, requiring a small boiler at the pit and a man to tend it, or else long expensive pipe lines from the main boiler house, with accompanying low efficiency of the steam by cooling and condensation enroute to the pit.

This method, however, is of great utility in many places where but little water is to be removed, and steam is available at no great distance. It is very simple in operation.

3rd. Bucket Elevator.—Another method of doing the work is by the use of the ordinary bucket elevator. The elevator suited to this class of work would preferably be that of the link belt or chain variety. The ordinary rubber or canvas belt would not answer so well on account of the continual soaking in water, and the cutting action of the sand and gravel.

By using large cups placed near together on the chain, a very large amount of water could be raised in a given time. The power to operate a rig of this type would best be supplied by a small gas or gasoline engine, or by a small portable steam engine as second choice. It might even be operated by horse power.

4th. Farm Windmill.—The use of a common farm windmill has been successful in draining a small clay pit for many years at Groveport, Franklin County, Ohio. The pit supplies ample clay for a moderate size roofing tile plant, and is located on a river bottom, where water is collected freely. As stated before, draining shale banks is usually an easy matter as most of them are side-hill workings which can be well drained by simple ditches.

5th. Suction or Piston Pump.—At one shale-pit, that of the Western Roofing Tile Co., at Coffeyville, Kan., the shale lies at a level below the general surface of the prairie, and hence artificial drainage is necessary. At this plant, a three horse-power gas engine is employed to operate a regular suction or piston pump which is placed at a sump or collection hole at the lowest point of the pit. The water from the rest of the pit is brought here by ditches, and the pump delivers it to a point outside of the workings.

At the one company which was mining its shale, the Murray Roofing Tile Co., of Cloverport, Ky., the strata happen to be dipping away from the plant, so that the drainage of the mine tends to collect always

at the farthest point of the workings. This is a common but unfortunate condition in mining, for it means the working face of the mine tends to be wet, while the old or abandoned workings are usually dry. The only available method to drain such workings is to put down sumps connected with the working faces of the rooms by shallow ditches. By pumping the sump dry daily or continuously if necessary, the working faces may be kept reasonably clear of water. Sometimes in outlying points, it is necessary to use a water car, or water-tight box or tank, which is filled by pumping or bailing the water at the working face and emptied either outside the mine or in a sump or ditch connecting with the outside. This is an expensive way, but often cheaper than a pipe line and power pump.

Underground workings are very apt to be much worse to drain than surface pits. The latter are subject to evaporation by the wind and sun's rays, and only fill up from rains, while mines are usually fed by springs or underground seepage which runs constantly. So that the provision of a steam pump, compressed air pump, electric motor driven pump or gas engine pump is apt to be a necessity. This condition exists at the Cloverport plant, which uses a steam pump for this purpose.

Clay Storage.—The plant that has for its source of material an open shale bank is in a much better position for a continuous supply of clay than one depending upon an open clay-pit, owing to the fact that the rains do not interfere nearly so much. The shale is much harder and more compact, and does not soften and become difficult to shovel or grind as a plastic clay does. At the same time, after a long,wet winter, it is often found that the shale with its overburden of plastic stripping or of partially weathered shale has become too wet to work. It possibly may not be enough to prevent its being ground, but enough to greatly interfere with its being screened.

There are, during the year, many days of inclement weather, in which men are loth to work, and even though they work their output would be far below the average. To overcome the above conditions, nearly every roofing tile plant using shale has made provision for the storage of dry shale during the summer months, in order to carry them over the stormy days, or to enable them to mix dry shale with the wet sticky shale fresh from the quarry, which is certain to be encountered during the spring months.

At some of the plants, provision is only made for a supply equal to a few days' run, or even a few hours' run, while in others a supply equal to six or eight weeks run is housed. Inasmuch as this matter of storage of clay is one intimately concerned with methods of transportation of the clay from the pit to the plant, it may properly be considered in connection with that topic.

TRANSPORTATION AND STORAGE OF CLAY.

The method of transporting the clays from the pits or mines to the point of their storage or use is a matter much influenced by local conditions. Without attempting to discuss all the modes by which such work is done, those which were actually found in use were as follows: (a) Wheelbarrows, (b) Common scrapers and wheeled scrapers, (c) Quincy clay-gatherers, (d) Horse dump-carts and dirt wagons, with sectional slat bottoms.

Taking them up in turn:

Wheelbarrows.—The extent to which this most expensive and uneconomical mode of transporting materials still prevails in clay works is surprising. It is a common thing, in fact the usual thing, even in brick plants which use from three to five times as much clay as roofing tile plants, to find the clay undergoing one handling by wheelbarrow. The expense of overhead trestles, chutes, elevator storage-bins, or other means of using gravity or power to avoid hand labor has seemed too great in hundreds of plants where the daily labor bill for doing this work runs into large sums. It is not uncommon to find even two and in some cases three separate handlings of materials before they reach the grinding machinery.

It is probably allowable and proper, with only a tonnage of 50 or 60 per day, to use wheelbarrows *once*, at the clay-pit with a short haul, measured in a few feet or yards. But it is bad management when a wheelbarrow trip is extended to a distance of a hundred feet, and it is bad engineering when clay once lifted by man-power on a shovel has to be lifted by man-power again, prior to grinding.

Scrapers, Common and Wheeled.—The effective radius of action of a common scraper, carrying $\frac{3}{8}$ to $\frac{1}{2}$ of a cubic yard when heaped, is not more than a hundred yards. A travel exceeding that amount is costing more than is economical, for the number of trips per day is limited and a team is slow and cumbrous in turning and maneuvering for a load or for the dump and not rapid when in actual transit between terminals. The large wheeled-scrapers, whose capacity is from $\frac{3}{4}$ to $1\frac{1}{4}$ cubic yards, are much more effective and may properly be made to travel even up to 200 or 300 yards, though of course the shorter the travel the more economical they are. When once the clay is in a scraper of any type, it should never be shoveled after that time—gravity or power apparatus should always be provided for its reception and future handling.

Quincy Clay-gatherers.—These machines, from the standpoint of transportation, are about like the wheeled-scrapers. Their capacity is no larger, and their effective radius of action is therefore small. If worked over large fields, their capacity per day is quite limited. It is better to use the gatherers to do their specialized work of loading

and gathering, and to provide dumping stations in the fields, from which the clay can be loaded by gravity and trasported more quickly and more cheaply by wagons or cars.

Horse Dump-carts and Dirt Wagons.—A horse-drawn vehicle capable of hauling loads of considerable size, such as from 1½ cubic yards up to 3 cubic yards, can be economically used for transporting clays considerable distances. Instances of such transportation over mountain roads for distances of 10 or 15 miles are on record, but the cost of the clay of course was rendered abnormal and made a heavy tax on the company using it. Instances of a haul of 2½ to 3 miles, with a change of level of 300 to 400 feet, are on record for plants which have operated thus for 20 years, with considerable daily tonnage of brick and sewer pipe, but here also the cost, while not prohibitive, was high, and was a handicap in times of close markets. Hauling a wagon-load a mile is quite within reason, and permits the making of 10 or 12 loads per day.

In the fourteen roofing tile plants studied, five were using wagons or carts for transporting their clays. Two of them were located well within the limits of cities of a considerable size, so that other haulage, unless it should have been by tram-road, was out of the question. At the Alfred, N. Y., plant of the Ludowici-Celadon Company, the distance and route to be traveled would have made a tram-car system of hauling and maintenance very expensive, the distance being something over a mile, and unless a right of way could have been obtained along the public thoroughfare, it would have been necessary to have purchased a right of way through expensive village lots for nearly a mile and a half. In such a case, the wagon was probably the last resort.

In the case of the Huntington Roofing Tile Company, Huntington, W. Va., it was found that they were drawing their supply of shale from two banks, which are in different directions, distances and elevations from the plant. Their No. 1 bank, which is possibly three hundred yards from the pan shed, could be reached easily by a tram-car line, but bank No. 2 would be rather difficult to reach by car. Their use of wagon haulage at each bank is, therefore, probably justifiable, in that it permits them to keep a uniform mixture of their two shales, by hauling the desired quantity from each.

At the plant of the Alfred Clay Company, Alfred Station, N.Y., the shale was being hauled by wagon from a bank on the opposite side of a ravine, across from the plant. The plant being at a somewhat higher level than the shale-pit, it would seem that an inclined tramway could have been installed here very nicely and the shale handled at materially less cost. At present the material has to be hauled up a long winding hill, in very laborious manner. In general, it seems, then, that teaming is a commercially possible method of transporting for short hauls of a mile or less, but that it can scarcely be considered cheap for

distances of over a few hundred yards. Its use in many cases, like two that have been cited, is due to local conditions which rule out the use of mechanical power.

Tram-cars, Pushed by Hand or Horse.—The advantage of the use of cars is the great reduction in traction and the therefore greater speed and lower use of power, or what amounts to the same thing, the larger amounts which comparatively feeble power can transport. Also, cars permit of easy and varied modes of automatic discharge, adjusted in each case to the track systems or bins or chutes leading to the pans. The capacity of cars usually runs from one to two and one-half cubic yards.

The only illustration of the use of the hand pushed cars met was at the Detroit Roofing Tile Co., where cars were used to bring the clay from the margins of the bank to a central dumping point, from which a conveyor took the clay into the plant. The distance to be traveled was small.

Tram-cars, Transported by Mechanical Power.—In this group, we find the largest number of installations in clay works in general, and a considerable proportion among the roofing tile works. The modes of applying mechanical power are various, such as (1) cable-roads, lowering the clay down hill, or hauling it up hill or horizontally with tail-rope haulage; (2) steam locomotives or dinkeys; (3) electric motor haulage.

At the Western Roofing Tile Co., Coffeyville, Kan., where the material must be elevated from a pit below the plant level, an inclined track is used, with an end dump car.

Fig. 52—Shale Bank and Car of the Western Roofing Tile Company, Coffeyville, Kansas.

The above cut shows the car, loaded, ready to be hauled up the incline by an ordinary winding drum with friction power and friction brake.

It will be noticed that this car is provided with an extra set of wheels placed on the main rear axle, which was made longer to accommodate them; these wheels do not run on the hauling track, but when the car reaches the point where it is desired to dump the load, the main track at this point becomes horizontal, and an extra set of rails are placed just outside of the regular track, where these outer rear wheels engage on them and come into action. These outside rails continue up at the previous angle of the main track, so as the car moves forward the front end moves in on a level track, while the rear end is raised higher and higher until the load slides out of the front end of the car by gravity. This style of self-dumping car costs very little extra, gives very little trouble by accidents or repairs, and can be commended as an ingenious and useful tool. It should be said that this company built its own cars.

The United States Roofing Tile Co., of Parkersburg, W. Va., uses another style of car, a side dump, made by E. M. Freese & Co., of Galion, Ohio. The conditions at this plant are different in that the shale is in the neighborhood of a hundred feet above the level of the plant, so that instead of using a cable and power winding drum to elevate the cars, a cable and friction drum without power is used to lower them down the incline.

In this instance, advantage has been taken of the power developed by the loaded car going down the incline to haul the empty car up. After the first installation has been made, this system is self-supporting; that is, no outside power is supplied to operate it.

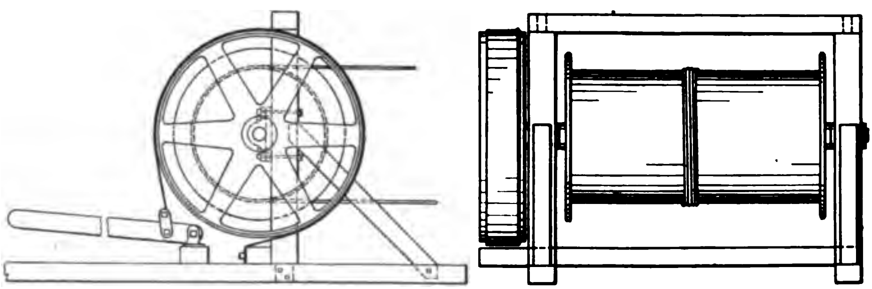


Fig. 53—Home-made Winding Drum, in Use at United States Roofing Tile Co.

It will be noted that this drum is a very simple affair; with the exception of the iron work, it was built by the company's carpenter. The staves of the drum are of oak, about three inches by five inches, and five feet long. The brake wheel is an old band wheel, and the brake band itself was a piece of kiln band-iron, seven inches wide by three sixteenths of an inch thick. It will be noted from the illustration that there are only four laps of the cable about the drum. In fact, two would have been sufficient.

The object in having the drum so long is to provide travel space for the cable laps. When a car is to be let down the incline, the cable laps are either to the right or left hand flange. As the drum revolves, the cable travels across the face, reaching the opposite side as the car reaches the foot of the incline.

Another feature of this equipment is the three rail tramway, instead of the usual complete double track. In order to save on the construction, which was high on account of costly trestling, the company made the trestle work narrow, and a three rail track system was constructed. At the passing point, or half-way down the incline, it was necessary of course to put in a double track or switch for a distance of thirty feet to allow the cars to pass. At this passing point the rails are so cut and laid that no attention has to be given to make the cars take the proper route.

The method of operation is as follows: In the beginning the first car up the incline had to be taken up by block and tackle; when loaded it was run out on the main track in front of the drum where it was hooked onto one end of the three-fourths inch steel cable. At the lower end of the incline an empty car was hooked onto the other end of the cable. The full car was then started over the brink and proceeded on down the hill, its speed being controlled by the friction band, and the up car passed it at the switch. As the loaded car reached the bottom, its impetus carried it on into the storage shed, and the empty car was pulled over the brink of the incline and out on to the level of the pit floor. Both cars were now uncoupled, the loaded one moved by hand through the shed to the desired point for dumping, a catch-pin was removed, and the load, which was purposely a little overbalanced on the dumping side, immediately caused the car to tip to an angle such that the charge slid out. The car was then righted and run back to the loose end of the cable and hooked on, ready for the up trip. At the upper end of the line, the second car was loaded and made ready to lower. This system requires two men, one at either end, besides the loaders.

Where the elevation of the shale or clay bank is such that this system can be used, it is to be recommended on account of its simplicity and the low cost of operation.

At the New Lexington plant of the Ludowici-Celadon Co., the cars in use were made by the Star Manufacturing Co., of New Lexington. The car is a heavy wooden one, strongly ironed, and for dumping is provided with two hinged wings which meet in the center when the car is closed, and which swing down vertical when the bolt is withdrawn, leaving the bottom of the car wide open for the full width and two-thirds of its length.

At the above plant and at the Parkersburg, W. Va., plant, also, the shale pit is at a somewhat higher level than the factory, so that the

material must come down an incline. The grade, though, in this case is rather low, so that the cars, which are provided with good brakes, are loaded and started down the incline without use of any cable. A man rides the car down, controlling its speed by the brakes to suit himself, it only being necessary to apply a very little pressure to stop the car at any point.

At the foot of the incline, the car enters the stock shed, and is allowed to run on into the shed to the desired point. Here a latch is released, and the two hinged wings forming the bottom of the car swing open, allowing the load to drop through between the track rails to the floor of the storage shed some twenty feet below. The bottom wings are then pulled back into position by a chain winding up on a shaft and locked by a ratchet. The car is then pushed out to the foot of the incline, where it is hauled up the incline to the bank by a horse. This horse has been trained to follow the load down at his leisure, in time to pull up the empty car.

Fig. 54—Shale Bank of the Ludowici-Celadon Co., New Lexington, Ohio.

At this plant the short distance of the material from the plant makes it possible and economical to move the shale from the bank to the shed in the above manner, and the low grade would make operation with a friction drum difficult. This plant is unquestionably handling as much or more raw material than any other roofing tile plant in the country. This plant affords one of the best examples of a proper provision of clay under cover in storage for use in bad weather. They

have a shed 60 feet wide by 150 feet long, with the track supported on the bottom chords of the roof trusses, about 20 feet from the floor. This whole immense space once filled would enable them to work for weeks without any other supply. A conveyor is used to move the material from the shed to the dry pans.

The Murray Roofing Tile Company, of Cloverport, Ky., as mentioned before, works a mine to win its shale. The entrance to the mine is about 100 yards from the plant, and at a level a few feet higher than that of the plant. In order to get storage room, the track has been carried into the storage shed at a slightly higher level than the mine entrance, so that the cars run back to the mine by gravity after dumping. (See Figure 50.) To bring the cars from the mine a simple winding drum is used. This drum is located at the inner end of the stock shed, and is belt-driven.

At the Ludowici, Ga., plant of the Ludowici-Celadon Company, the horizontal track system a mile or more long from the clay pits to the works is used, and the cars are hauled over in trams by mules. The face of the pit is kept vertical, so that the cars can be run close up parallel with the working face. The workmen are stationed at various intervals and levels, the bank being worked in steps, of single spadings deep, one man working on each step. (See Figure 42.)

Railroad Cars.—At two plants, where the materials and plants were widely separated from each other, viz., The Mound City Roofing Tile Company, of St. Louis, and the Cincinnati Roofing Tile and Terra Cotta Company, of Cincinnati, Ohio, clays are shipped in full-sized railroad cars. At the former plant the shale is shipped a distance of about 25 miles, while at the latter the material is shipped about 100 miles.

After the cars of material reach the plant they are for the greater part of the time unloaded by shoveling into the dry pan direct, but at other times the clay is carried into large storage sheds for the winter use. When the sheds fill up to a point where the men can no longer put in more material by shoveling from the car, wheelbarrows and runways are resorted to in order to get the clay farther back into the shed.

This method of handling the raw material is quite costly, for it must be wheeled for a third time when needed for use. It would seem that a short portable conveyor reaching from the side of the car back into the shed as far as desired could be easily arranged. It would be necessary, of course, to have a countershaft extending the full length of the shed, with driving pulleys at regular intervals where the conveyor could be attached. When one part of the shed was filled it would only be necessary to move the conveyor on to the next section.

When it became necessary to draw on the reserve stock of material, it would again seem advisable to use a conveyor extending laterally in the shed, so that a man stationed at any section of the storage shed

could shovel direct onto the conveyor, which in turn would deliver the clay to the dry pan for grinding. Whenever the distance exceeds a few yards, one man could easily move as much material in a given time by means of a conveyor as three men could move with wheelbarrows.

The Conveyor System.—A little illustration of the use of the conveyor other than the suggested case just mentioned is that of the Detroit Roofing Tile Co., of Detroit, Mich. Their conveyor reaches from the grinding room out into the clay pit, a matter of fifty or more yards distance. This conveyor is merely an endless rubber or cotton belt, about fifteen inches wide, carried on rollers at intervals of a foot or so apart. The power to drive the belt is supplied at the discharge end by a geared friction wheel and tightener.

At first it was possible to shovel the clay direct from the bank onto the belt, but as the pit enlarged it was necessary to install two hand push cars, shown in the illustration. By observing this figure, No. 56, it will be seen that the clay is dug in benches, or spadings, each car being loaded with a definite number of shovelfuls from each bench, thus bringing every level of the bank equally from top to bottom. When a car is thus loaded, it is pushed to the conveyor by hand, and there unloaded by hand. There are limits in the matter of elevation to which this system of clay handling could be employed, but by means of cleats or flites fastened to the belt the material could be carried down or up a rather steep angle—at least 25 degrees. The development of conveyor systems, with enormous carrying capacity and with adjustable dumping points, has reached an advanced stage of development in many lines of industry. The limitation which prevents their wider use in roofing tile manufacture is the small tonnage they are called on to handle and the relatively great expense for installation and up-keep. However, simple, straightaway belts of moderate capacity are no longer costly, and they are very simple and efficient in use.

THE GRINDING OF ROOFING TILE CLAYS.

The purposes in view in the grinding of clays preliminary to manufacture by the plastic, or stiff mud, process are generally twofold:

First—To break up any impurities or obnoxious minerals which may happen to be present in coarse form, and disseminate them uniformly through the mass—in other words, to homogenize the clay so that any one cubic inch of it will have the same physical and chemical properties as any other cubic inch. It often happens that the minerals composing a clay or shale are not obnoxious if properly distributed, but if left in coarse lumps they would be classed as impurities—quartz or sand-rock, for instance, which is likely to be a really desirable addition to the clay if it can be properly distributed. It also generally happens that other minerals commonly found in clays, such as limestone or

Fig. 55—Conveyor at Detroit Roofing Tile Co.,

Fig. 56—Clay Pit at Detroit Roofing Tile Company.

iron ore, are regarded as impurities under practically all conditions, either before or after grinding, but by fine grinding and more even distribution their evil influence is much reduced.

Second—To create plasticity in clays which have been so long stored in rock form in the earth's crust that they have lost this property to a large extent, or rather, it lies dormant and undeveloped. The grinding makes it possible to apply the softening power of water on an enormous surface area at once, and also to create a plastic paste out of the finer portions of almost any rock powder. There are clays so hard and stony that no great or sufficient plasticity can be developed, even after persistent grinding with water in powerful machinery, but these are exceptional.

These two purposes are most commonly both represented in the grinding treatment of a given clay, but in some cases only one purpose may be in view. In general, in soft, plastic, glacial or alluvial clays there is no need of grinding to develop plasticity—in fact, they more often need some anti-plastic body, like sand, to cut down the excess of plasticity. Grinding, in such clays, is therefore chiefly for the dissemination of the harmful impurities, and in some few machines their removal. A grinding treatment of such clays is often very perfunctory, and sometimes omitted entirely. In many shale clays the homogeneity of the material itself is very good, and no impurities of importance exist, and here the grinding is wholly with a view to obtain a plastic paste.

Grinding treatments for the plastic process of manufacture, whatever object, are divisible into two groups—wet grinding and dry grinding. It will be understood that the following remarks are not intended to apply to the slip or washing process of preparation for pottery clays, or to the dry press process, which finds little if any use as yet in roofing tile manufacture. In general, wet grinding is practiced where defective plasticity is found, as it is very much more powerful in developing the latent plasticity of a clay than any other treatment. At the same time, the ability to size the grains and secure the crushing of all of the coarse impurities, and thus secure high homogeneity, is largely lost in wet grinding. Hence this threatment is usually applied to the harder shale clays and fire clays, and when applied to very plastic clays the grinding is very short-lived and imperfect.

In general, dry grinding is practiced where the material is unhomogeneous naturally, and where its lack of homogeneity would be severely felt in the product if steps were not taken to overcome it. It is followed ordinarily by screening, which establishes the limits of the size of any particles in the clay, and is therefore the guarantee of homogeneity. The screened powder is then to be converted to a plastic paste by a subsequent process. Thus it is seen that the dry grinding and wet grinding operations are really more than alternative routes to the same

goal. To a considerable extent they produce different results and are applicable to different clays.

The determination of which treatment should be given in any individual case is a matter of judgment with the operator. The wet treatment is slower, more costly, and has less control of the homogeneity of the product, but produces by far the best plasticity, and can be used where plasticity can be gotten in no other way. In general, any clay *can* be treated by this process, but it is rather uncommon to use it except where necessary on account of the reasons given above.

The dry treatment is faster, cheaper, produces a more homogeneous paste, but of deficient plasticity. It can be used with clays of good and moderate plasticity, but not very well with those of low plasticity. Wherever it can be used it is very likely to be selected for the reasons above.

With these preliminary statements, setting forth the theory of the grinding process, the different modes of doing the work will be considered. As in the case of winning, and in short throughout this report, no attempt will be made to discuss all possible modes of treatment. Those actually found in use in roofing tile plants will form the basis, with such suggestions of other processes as may seem worth while.

Grinding With Rolls.—The roll is one of the simplest and oldest forms of grinding machines. Essentially it consists of two cylinders or cones, whose surfaces are in close contact or held closely parallel to each other. Their axes must be in the same plane, and in the case of cylindrical rolls they are parallel, but in the conical rolls the axes are inclined to each other by an amount proportional to the taper of the cones. By revolving these rapidly toward each other, any object caught between them tends to be nipped and carried through. If it is not too large and too hard, it will be crushed in passing; if it is too large it will not be nipped, and will simply roll around on the surface of the rolls without effect. If it is small enough to be nipped, but too hard to be crushed, one of three things will happen—the rolls will stall and stop, or they will spread apart to let the hard particle through, or they will break. In practice, they are held to each other by heavy springs, which permit them to spread momentarily in passing an exceptionally hard piece, rather than accept the other two alternatives of stopping or breaking.

Rolls are designed for two different ends: First, as a wet grinding machine for crushing stony, plastic clays, and for rejecting the rocks or hard portions which are too large to fall within the angle of nip; second, as a dry grinding tool for pulverizing large quantities of materials of nearly uniform size of grains. The commonest use of rolls in this way is as a tailings grinder, to finish the grinding of small particles which are partly reduced, but not enough so to pass the screens.

Wet Grinding Rolls.—These constitute the most simple method found in use for crushing soft plastic clays. Two roofing tile plants were using this method: The Detroit Roofing Tile Co., at Detroit, Mich., and the Dixie plant of the Ludowici-Celadon Co., at Ludowici, Ga. The clay of the former company as stated before is a fine grained blue and gray, alluvial clay, soft enough to be won by spading, and hence very easy to grind, and so plastic as to be very difficult to grind in a strictly dry grinding machine, like a dry pan. The clay coming from the pit by conveyor feeds directly into a pair of smooth rolls, made by the Horton Manufacturing Co., of Painesville, Ohio. These rolls are differential, one being a small roll driven at high speed, and the other a larger and lower speed roll. They are set up within a small fraction of an inch of each other. The small roll, about nine or ten inches in diameter by two feet long, runs at approximately five hundred revolutions per minute, while the large roll, about eighteen inches in diameter, makes but one hundred and fifty revolutions per minute. The peripheral speed of these two rolls is quite different, so that when clay is fed into the machine, it not only squeezes and crushes it, but also shreds and tears it apart as well. The lumps or pebbles are caught up and crushed very fine, the size depending of course on the opening between the rolls. This machine is able to take clay either dry or wet and carry it through. Ordinarily as the clay comes from the bank it is of suitable water content for stiff mud work, but if too dry, a little water is supplied immediately after passing the rolls. As the clay drops down from the rolls it falls directly into an open topped pug mill, eight feet long, also made by the Horton Manufacturing Co. The clay slowly works its way through the pug mill, and drops onto a platform from whence it is picked up by a man who tosses or slams it into storage or aging bins, being very careful to get the clay well packed in the bins or pits. It is here allowed to stand about three days, enabling the water content, if unequally divided, to equalize itself through the mass by diffusion. A more uniform product is thus obtained.

In the Dixie plant at Ludowici, Ga., as was noted under the heading of winning, they are working a very fine grained plastic clay, which rests upon a water-bearing sand; in fact, some of the clay is at times dug out of water (Fig. 42). It therefore usually comes to the plant in a wet, semi-plastic condition. It should be mentioned here that for reasons discussed later, a small proportion of a very sandy shale, previously ground and screened, is added to each car of the plastic clay as it comes from the field. This shale is, of course, in a dry, dusty condition, very different from that of the clay.

The car, with its double charge, proceeds up an inclined trestle to a hopper, where it is dumped. This hopper stands immediately over a pair of smooth rolls specially made for the company. These rolls are very large, and run at a relatively slow speed. They are two feet long

and thirty inches in diameter. The rolls being of the same size and running at the same speed, the clay in passing through them is crushed or squeezed, rather than shredded or torn apart. After passing through the rolls, the clay drops into a combined pug mill and auger machine made by J. D. Fate & Co., of Plymouth, Ohio.

This machine is used as a closed top pug mill, rather than a true auger machine, as it does not turn out a finished product. As the clay issues from the end of this mill it is taken by men and slammed down hard into soaking or aging bins, where it remains about one week. This allows the excess water in the field clay to come in contact with every particle of the dry ground shale that has been added to it.

In this plant is illustrated a treatment admirably suited to their material. The homogeneous quality of the clay is such that actual grinding or reduction of size of grain is not needed. What is needed is a thorough mixing of the plastic clay so that the layers representing different spadings shall be wholly obliterated and a new ingredient entirely foreign to the clay itself shall be uniformly disposed through it.

In their mechanical treatment, the crushing effect of the rolls is followed by the combined work of a double shaft pug mill and the compressing effect of an auger machine, which not only thoroughly mix the ingredients, but compress them into a dense mass, excluding the bulk of the air, and bringing the particles of clay substance into close contact.

Dry Grinding and Stone Separating Rolls.—Owing to the wide distribution of excellent alluvial clays and shales in the United States, very few persons will attempt to use a glacial clay for any but the commonest kinds of material. Only one plant was found using a glacial clay for roofing tile manufacture, viz., the Chicago Heights plant of the Ludowici-Celadon Company. Their clay is an average sample of the glacial clays which characterize the Chicago district. These clays are still plastic as they are taken from the pit. They are fine grained in the main, but very badly mixed with coarse and fine glacial pebbles of all sorts. Of glacial clays in general, owing to their origin in ice sheets moving across the earth's surface, it is to be expected that they will be heterogeneous in nature, and composed of a mixture of what they have passed over, viz., boulders, gravel, sand, rock-dust and clay substance. The stones may vary in size from boulders of enormous size down to the point where they lose their identity, and are called gravel. The ingredients may not only vary widely in size, but in proportions also, and they may also have a wide range in composition, i. e., different minerals and different amounts. Thus the man who attempts to work a glacial till is not only confronted with the working of a very impure clay, but at the same time a very variable one.

The Ludowici Company has been working a material of such characteristics since about 1893. They have not only succeeded, but have

proved that without question good roofing tiles can be made from this and similar heterogeneous clays elsewhere. This company, apart from the original error in judgment, in establishing such a plant on such a clay, has faced these most trying conditions with fine determination, and has unquestionably brought more real engineering science into use in surmounting its difficulties than any other roofing tile plant in this country. It is not meant that other plants could not have done the same, but the nature of their material has mercifully not required it.

The problem of successfully working a glacial clay begins in the clay-pit. By referring back to the discussion on winning, it will be seen that this company is using the Quincy clay-gatherer, which is undoubtedly the finest tool in use for the careful averaging of the clay as it is taken in the field. The clay is dumped by the clay-gatherers in a stock house or storage shed of immense proportions, holding clay enough for several months' operation in the winter, when the bank is too wet for possible winning. Through this stock-shed, a central conveyor-belt runs, which can be loaded by shoveling from any point in the shed.

This conveyor-belt delivers at one end of the shed to the first machine—a pair of conical, dry-crushing rolls, smooth surface, set one inch apart, and running at 75 revolutions per minute. These rolls crush the lumps of clay and smaller pebbles; any stones that are considerably larger than the opening, i. e., too big for the angle of nip, gradually work their way to the large end of the cones, where they fall out into a wheelbarrow, to be removed. The use of these rolls is chiefly for the sake of their qualities as stone separators, but the next step in the process would hardly be successful if the clay had not been first crushed and shredded.

In a day's run of ten hours, nearly ninety tons of clay pass through this small pair of rolls. In size they are about two feet long by twelve inches at the large end, and seven inches at the small.

It will be understood that the gravel stones smaller than the space between the rolls have passed on through untouched. In this condition the clay-mixture could not be used for roofing tiles or any product. Finer grinding must be resorted to; in fact, it must be extremely fine in order to prevent the lime-pebbles from pitting or "popping out" in the burned tiles. No instance was observed in the roofing tile plants of the country of the use of the dry-crushing rolls for very fine sizes, i. e., tailings crushers, but such a use is common in other branches of the industry. No instrument is more efficient or does more work for the power used, in crushing an even-sized granular material than rolls.

Grinding With Dry-pans.—This machine is so well known in all branches of clay manufacture that no space will be used in describing its construction. It is in use in all countries where clay working has progressed beyond the rudimentary stage. No other tool wholly takes

its place as a rough and ready grinding machine, in which the material comes to it in widely varying sizes, from large lumps of several hundred-weights down to dust; in widely varying hardness, from "niggerhead" boulders in glacial clays and carbonate of iron concretions in shales down to soft crumbly earth; in widely varying degrees of plasticity, from sticky paste after a rain up to bone-dry materials returned from the driers for reworking; and in rates of feeding, varying from overloads of 300 or 400 per cent. down to frequent periods when the machine is running empty. All these irregularities occur in any works, and on every dry-pan. No machine that cannot give a good account of itself under such conditions will ever displace the dry-pan as a clay-grinder's main reliance.

There are a number of different designs on the market, varying in various more or less important details. There are over-head driven pans, versus under-geared pans. The latter are common in ironworks for wet-grinding iron ore for puddlers' "fix," but they are not common in clay works for either wet or dry use. The advantages claimed are the low frames, the accessibility of the pan itself, and the housing of the gears under the pan free from dust of the shop. On the first and second points, no argument can be raised, but the gears underneath are very doubtfully better placed as far as saving the gears themselves from wear and tear is concerned.

There are wooden framed versus cast-iron framed, and the latter versus the structural-steel framed pans. The former are fast passing from use and the latter are coming in. The vast majority of pans now in use have cast-iron frames. The wear and tear on cast frames is very severe, and breakage is not uncommon if the bolts are allowed to work loose.

There are pans with separately suspended mullers and those with yoked mullers, i. e., both on the same shaft. The ends of the shafts are held in position by side guides, but are free to move up and down to accommodate the various sized lumps of material passing beneath the mullers.

With a continuous shaft, i. e., the yoke pattern, the lifting of one muller throws the opposite one into a position where it is running on the outer edge of its face, hence doing very little work, while in the case of the independent mullers each works without interference from its neighbor.

The propelling force of the mullers is derived through their frictional contact with the floor of the revolving pan, one muller moving in one direction and the other in the opposite.

It is claimed by the manufacturers of yoke-muller pans that they can get a larger tonnage per day through their pan than the other type, their contention being that with both mullers on the same shaft, they obtain more weight to crush the material in hand, and can hence grind more in a given time. This claim can hardly be substantiated, for it

is the repeated blows of the mullers that break down the hardest material, and not their mere weight. Their combined weight can never be concentrated on one end in any case. It may perhaps be conceded that the yoked muller-pans runs smoother and with less jumping than the independent muller-pan and may possibly, by reason of this, wear longer, but as to their giving an extra output it will not be agreed to without more figures from some uninterested source. Either style of pan, though, proves successful in a roofing tile plant, because here quality of work is considered more largely than quantity. In no case are the pans likely to be run to their full capacity, for the tonnage of clay to be ground is relatively small and the problem is quite different and much easier to meet than in brick manufacture, where output is much more important.

Pans are also usually constructed with scrapers underneath, which revolve with the pan floor, dragging the c ay ahead to one point of delivery on the circumference, but in some instances large concrete brick or stone foundations are built with sufficient depth to permit gravity feed of the powdered clay to the point of delivery outside of the base. This method reduces the friction of the pan considerably, and seems destined to find general acceptance wherever the local situation permits the necessary depth of pit.

Pans are also arranged with direct drive, from coupled engine shafts (rare); direct drive with geared electric motors, a new form still rare, but likely to become much used; and belt driven, comprising the vast majority. The belts are arranged to drive pulleys placed inside the main bearings of the top frame, or over hanging pulleys, or pulleys with separate outboard bearing. The belt drive, with either self-contained or outboard bearing, makes a perfectly safe and satisfactory drive and is likely to persist in general use as the most generally convenient.

Besides these variations in the larger questions of design, there are innumerable smaller ones, such as chilled cast iron muller tires vs. special chrome or manganese steel tires; friction clutch vs. tooth clutch vs. fast and loose pulleys for starting and stopping; fixed vs. adjustable scrapers; and the kind of step or bottom bearing to carry the weight of the vertical shaft.

The step is one of the most essential features about a dry pan. In the ordinary pan, the weight of the pan bed, vertical shaft and gear wheel, the combined weight of the two mullers and their shafts as well as the eight hundred (800) to sixteen hundred (1,600) pounds of clay in the pan is carried upon this small bearing.

This means that a load of five or ten tons is carried upon a bearing not as a rule exceeding five inches in diameter. This bearing tends to heat very easily and unless proper oiling facilities are provided, it will prove very short lived. Ball-bearing steps have been brought out

from time to time, but they have made no impression on the market. The principal thing is to secure positive and copious lubrication. Nearly any step, if of adequate size, will stand well if it is kept thoroughly lubricated and clay dust and grit are kept out of it.

In selecting a pan one should try to secure one that is strongly built—not only strongly built but well built. By this is meant one that has every joint and bearing *planed* and *fitted*, every bolt hole *drilled* and machined bolts that properly fill the holes. There is not another machine about a clay plant that has to stand the rough usage that the pan is expected to endure.

Unless the pan is built as above stated, it will only be a matter of a short time until it will be creaking at every joint, consuming a great amount of extra power, and in fact pounding itself to pieces.

Pans of the other type, with cored bolt holes, can be seen in some of the roofing tile plants. In one instance a pan was found so poorly constructed that there were numerous bolt holes so out of line that bolts could not be put in at all, or had to be driven in. There is, however, a marked change in the last few years toward better clay-working machinery, and the machine manufacturers should be given credit for what they have done and proper encouragement to do still better.

As before stated the step or bottom bearing is very important. Select the machine having a large and easily accessible step, one that runs in oil and that can be opened easily for inspection.

The two most neglected points about a clay plant are: first, the dry pan step, and second, the elevator boot. The location of both of these parts is so inaccessible and so dirty, that the tendency to neglect them is strong. Unless the pan has a step that can be easily reached and easily taken apart, it is certain to be neglected. The pan tender will ordinarily not take the trouble and undergo the discomfort necessary to inspect the step, until forced to do so by the evident signs of distress from that locality.

It is entirely impossible for any one to say that all the virtues are to be found in any single design. There is no *best* pan in the sense of one filling all situations best. Of those actually found in use in the roofing tile plants of the country the following makes were recorded.

American Clay Machinery Company	7
Frost Manufacturing Company	3
C. W. Raymond Company	2
Bonnot Company	1
	13

Grinding by Disintegrators.—At the plant of the National Roofing Tile Co., Lima, Ohio, a method of grinding is used that is not to be found in any other roofing tile plant in this country, though the method is common in other branches of the industry.

This company is using a pulverizer manufactured by Williams Patent Crusher & Pulverizer Co., St. Louis, Mo.

The machine consists of a horizontal shaft to which are keyed a series of discs, through the circumference of which bars are run, and upon the latter are hung swinging hammers, which, by centrifugal force, fly straight outward on a line from the center of the shaft when the machine is rotated at high speed. The hammers swinging outward strike a very powerful blow, but the hammer is not rigid or inflexible, being held out merely by the centrifugal force and being free to bend back to the center whenever it comes in contact with a body heavy enough to overcome the centrifugal force. This acts as an ingenious protection against breakage by foreign material, like picks, bolts, shovels and the like falling into the hopper. The machine is run at a very high rate of speed, so that the material to be pulverized is subjected to many thousand blows per minute. The clay, being subjected to such severe treatment as this, is completely broken up before leaving the machine. It will be noted from the cut that the clay in the case of the National Company is elevated by the cup elevator, on the left side of the machine, to a point where it is fed into the hopper. Upon passing out it is again caught by a second elevator, shown on the right side of disintegrator. This elevator carries the clay to a sixteen mesh screen on the third floor of the building. That part of the clay which is fine enough to pass the screen falls into a storage bin while the coarse material is returned to the disintegrator by the chute shown in cut.

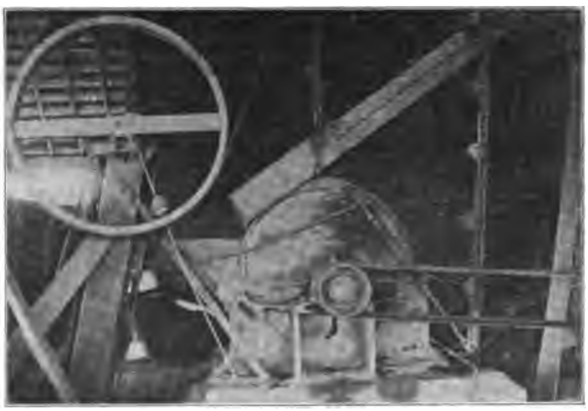


Fig. 57—Pulverizer or Disintegrator at Works of National Roofing Tile Company, Lima, Ohio.

It is found advisable to bring the clay to the disintegrator as dry as possible, and even then provision is made to steam heat the jacket of the mill in order to prevent the clay from packing or caking on it.

For clays of a dry, compact, fairly hard nature, this style of ma chine will unquestionably break up the massive lumps and reduce the

whole to a moderately fine powder at a good rate, varying with the size of machine, horse power used, and rate of feed. If the clay be a fat, sticky one, as in the case of the clay at Ludowici, Ga., it would prove impossible to work it through a disintegrator. Even moderate dampness must be guarded against as shown by the use of the steam-heated jackets in this style of machine.

The relative performance of a disintegrator versus a dry pan, which is the only other machine with which a comparison is at all apt, is still a matter requiring proof. Makers of both machines claim all the advantages for each. It is also certain that a big disintegrator, given the power and speed, will grind, at a furious rate, anything in the clay line, excepting wet clay. But any intelligent comparison must show the relative power consumption on the same materials, and the output per day per horse power used, and also the relative repair bills for a year or so. Such figures are not available. The use of the disintegrator has been known to clay workers for twenty years or more, but has made comparatively little headway in displacing the dry pan, while for harder and more brittle materials, less liable to pack or cake in the machine, the disintegrator is finding a very great market.

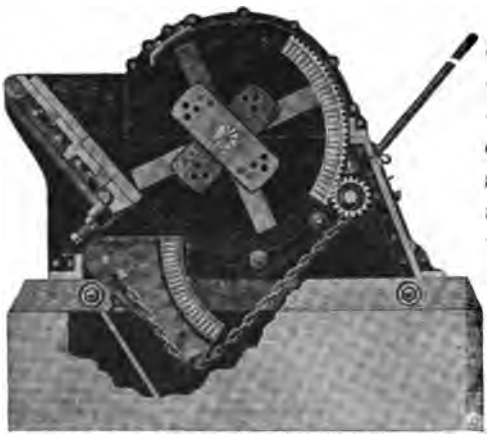


Fig. 58—Sectional View of Disintegrator.

Wet Grinding. — The preceding types of grinding machines are designed to operate on clays of various stages of dryness, from the cheesy consistency, as spaded out of a swampy pit at Ludowici, Ga., up to the carefully predried and heated clay at Chicago Heights, Ill. In all these cases grinding is followed by tempering, a second operation for the development of plasticity, before going to the ware-forming machines. There are two other processes of grinding in use which differ from the preceding in the fact that grinding and tempering go on jointly in one and the same machine, which delivers the plastic paste direct to the forming machinery.

The Chaser.—This machine, now rarely seen, was originated, or at least most largely used, in the Akron district of Ohio. It was employed in the sewer-pipe and stoneware plants which have been very numerous there for forty or fifty years—in fact, for years these industries thought they could use no other device. From Akron as a center, the chaser mills were sent all over the country in the sewer-pipe and stoneware trades, and they may still be found occasionally, though few if any new ones are being installed. The Akron Vitrified Roofing Tile Company used this machine exclusively for the tempering process for all the

earlier period of their existence. They were preceded in this direction, however, by the Bennett Roofing Tile Company, of Baltimore, Md., now dismantled.

The clay used at the Bennett Company was a soft yellow alluvial material. Upon being hauled to the plant by wagon, it was stored in bins until needed, then being wheeled by hand to the chaser, which was made by Turner-Vaughn-Taylor Company, of Cuyahoga Falls, Ohio. The clay to the amount of 800 to 1,200 pounds was dumped into the pan of the mill, water added, the mill started, and the work of grinding carried on for from twenty to thirty minutes per charge. The mill was then stopped, the clay shoveled out, and packed in bins to age a little before being pressed into tiles.

The construction of the machine can be readily understood from the following illustration:

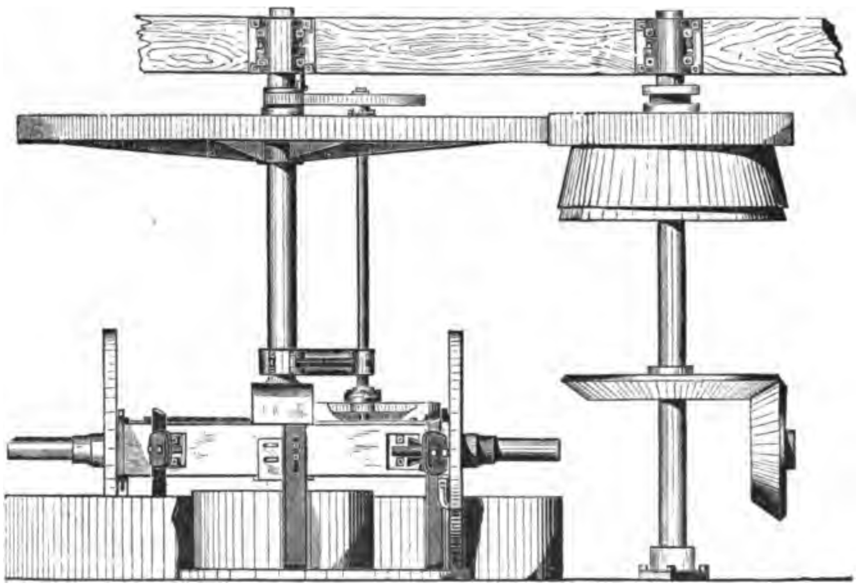


Fig. 59—Chaser Mill.

The machine differs from other pan grinders in the fact that the pan floor is solid, or stationary, while the grinding wheels run in circular or spiral tracks around the central vertical driving shaft; hence the name "chaser," for the wheels seem to be in endless pursuit of each other.

The action of the chaser cannot be considered efficient from the standpoint of power consumption, daily output of clay, labor required or homogeneity of product. It is slow, costly to operate, and not thorough. Nevertheless, it gives to its product, or at least its advocates so claim, a toughness and cohesion not attained by other forms of tempering appliances. Rarely will a person accustomed to the use of clay

from a chaser mill willingly accept clay from any other process as a fair equivalent. This idea is too universal among workmen, foremen and owners to make it likely to be wholly a prejudice. There is a foundation of truth, and the cause is to be sought in the peculiar variety of sizes of grains in the product. The principle of a dense structure requiring a variety of sized grains is known and recognized in cement work and mortar materials, and has been broached often in connection with the differences in strength and toughness of clays, and it is the probable cause of the peculiar tenacity of chaser-tempered clays. It will be at once understood that there is no screening or sizing process possible where wet grinding and tempering processes are employed, and the study of the product of a chaser shows a much wider variety of shapes and sizes of grains than do clays which have been screened dry. No matter how long the grinding is continued in this machine, some coarse particles will always dodge the narrow tread of the tempering wheels.

The Wet Pan.—The wet pan, as originally used, is simply a solid bottomed pan, of exactly similar variety of construction to that found in dry pans, into which raw clay is thrown in 800 to 1,200 pound charges, and ground and tempered in one operation and without prescreening or any final sizing of grains in the plastic paste. It is still used exactly in this way in the fire-brick industry, where charges of hard, flinty clays mixed with burnt "grog" are ground until enough plasticity is developed to permit hand molding of simple shapes. Often thirty to forty-five minutes are consumed in tempering a single charge.

This mode of operation, which justly entitles the wet pan to a place among grinding machines, is not employed at all in the roofing tile industry so far as known. The latter and common use of a wet pan is as a tempering machine, beginning with materials previously ground in a dry pan and screened to the requisite fineness for the product. It cannot be doubted that under these conditions the wet pan still acts as a grinding machine, and that tempering even for 2½ or 3 minutes, which is the usual time when screened clay is used, results in some increased fineness of grain. Nevertheless, the tempering or development of plasticity is the important feature, and the grinding is incidental (though more important than is generally conceived or admitted). For this reason, the further discussion of the machine will be deferred till the topic of tempering is reached.

Drying and Preheating of Clays Before Grinding.—The greatest obstacle in the preparation of clays by all-dry, semi-dry, or plastic processes, in short, by all processes except where the clay is reduced to a state of fluid suspension as in the "washing" process, is the constant tendency to clog up the machinery by reason of its strongly cohesive properties. These properties are essential—the foundation, in fact,

of the clay's value over other minerals, but they make clay preparation difficult and inexact.

Rolls, of all grinding machinery, are best able to deal with a clay in the cheese-like plasticity found in nature. Dry pans can handle a limited amount of such clay if mixed with some dryer material, but the capacity of a pan falls off very rapidly with each increase of water, over five or six per cent., and at thirteen or fourteen per cent. the pans will not put through $\frac{1}{8}$ or $\frac{3}{16}$-inch screen plates more than twenty-five to thirty-three per cent. of their normal output. With actual plasticity, the dry pan becomes impossible. Disintegrators are even more susceptible to hindrance from moisture than dry pans.

After a clay has been through a pan or equivalent, and is in the form of a coarsely granular powder, the screening still remains difficult if moisture exceeding five or six per cent. is present. Caking on the screen and covering the holes, agglomerating and rolling along on the surface without passing through, sticking fast in the elevator cups and refusing to dump, choking up spouts and runways, etc., are the troubles incident to dry clay screening. Water is at the bottom of all these troubles and thoroughly dry clay grinds and screens as easily as could be desired.

These difficulties all increase directly in proportion to the fineness of the powder which is to be produced. In order to get clay fine enough to make a good homogeneous roofing tile body, especially if it contains lime or iron minerals in lumpy form originally, it is sometimes necessary to dry the clay in advance by some artificial treatment. Winning in good weather, airing before gathering, storing in dry stock sheds for months before use, etc., are all still insufficient to permit fine grinding.

The best illustration of really fine grinding and of proper preparation for it was found at the Chicago Heights, Ill., plant of the Ludowici-Celadon Roofing Tile Company. They employ a rotary dryer, consisting essentially of a boiler shell about 4 feet in diameter by 30 feet long, supported near its ends, in a nearly horizontal position, by roller bearings.

Provision is made to rotate the dryer by a gear wheel encompassing the shell and driven by a pinion near the discharge end. The shell is inclosed in a brick furnace, with space left in which the heated gases travel around and encircle the entire mill. The heat is supplied from coal-fired furnaces along the sides of the discharge end.

Formerly the gases of combustion passed directly through the mill, bathing the clay in their travel, with water vapor, carbonic acid, soot and sulphur fumes. The effect of this was believed to be responsible for a scum or efflorescence of sulphates on the burned ware, so the present rig was devised, whereby the gases of combustion do not come in contact with the clay at all, but pass along the outside of the shell and up the stack at the feeding end.

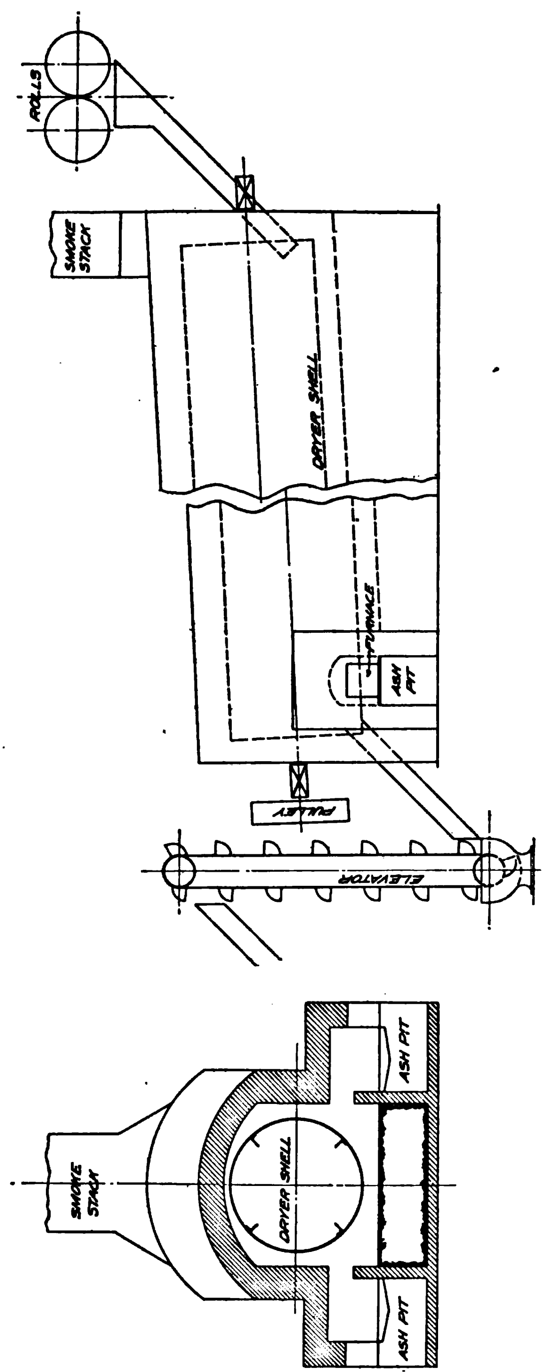


Fig. 60—Clay Dryer, substantially as arranged at the Chicago Heights plant, Ludowici-Celadon Co.

As the clay comes from the conical stone-separating rolls, in a fairly well shredded or disintegrated condition, it falls upon the inclined chute shown in the cut, and passes directly into the dryer. The dryer shell is inclined about one and one-half feet in its length, so as it rotates about 10 or 12 revolutions per minute the clay gradually works on through its entire length, being continuously picked up by four flites or blades, shown in the end section. These flites carry the clay nearly to the top of the shell before letting it fall, thus constantly stirring the clay up and exposing it to heat and air circulation. As the clay slowly reaches the hot end of the dryer, it attains a temperature of at least 212° F., although no attention is given to this point, except to see that the clay is perfectly dry at all times.

As the clay leaves the dryer it is caught up by a short cup elevator that discharges into the nine-foot dry pan.

A similar, but less efficient, installation has recently been put in by the Detroit Roofing Tile Company. In this case, they use three furnaces under the rotating cylinder.

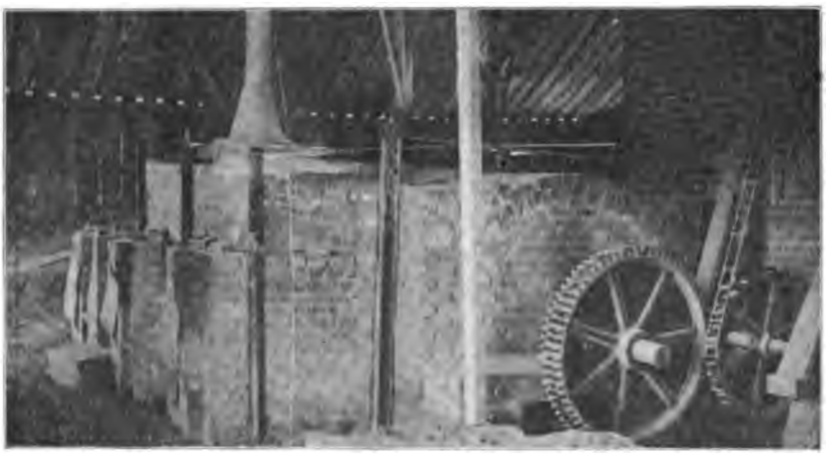


Fig. 61—Home-made Rotary Dryer installed by the Detroit Roofing Tile Co.

Such dryers, home-made in the two instances cited, but readily procurable from any one of a dozen prominent engineering concerns, especially those that cater to the cement manufacturing industry, are efficient. Their first cost, if home-made or built by a local shop from old boiler shell as a basis, may be kept small—under $1,000. If bought from a proprietary dryer firm, with furnaces and special feed apparatus, it may run from $2,000 to $4,000, according to dimensions and capacity and guaranteed evaporation. But by their use many clay works that limp along on one-third or one-half output every rainy day and close down all through the bad winter weather, could be made to turn out a good day's work all the time.

The cost of the treatment is comparatively slight. The power required to rotate the heavy cylinder is probably less than five horse power in some cases, and under fifteen in any that would be needed in a roofing tile plant. The fuel varies according to whether it passes through the dryer or merely around it, from one ton to three tons per day, or its equivalent in oil or gas. The feeding and discharge can readily be made entirely mechanical. The labor of operation may be confined to firing the furnace and this is done by automatic stokers in the Cummer and other good types. On the basis of drying fifty tons per day, and using two tons of coal, a fireman and ten horse power, the cost would normally not exceed 20 cents per ton and might easily be nearer 10 cents.

This kind of treatment is not a common thing, although its value is apparent and unquestionable. It happens, however, that the effect of this drying treatment is more complex than at first imagined, and that results are obtained from it which were not in the least anticipated by those who first installed it. This subject has come to light through the researches of Prof. A. V. Bleininger,[1] of the University of Illinois and the United States Geological Survey,[2] advance sheets of whose bulletin, in collaboration with Layman, have very kindly been furnished for notice in this report.

In the above article it has been shown that by taking a clay of high shrinkage, one which cracked so badly in drying that it was commercially impossible to work it, and preheating it at a temperature varying from 100 to 200 degrees above boiling point of water, it was possible to so reduce the shrinkage that the clay could be safely worked.

The test was applied to a clay found near Urbana, Ill., which is extremely fine grained, very sticky and plastic, but of low bonding power. Small samples of the clay were heated at 100, 200 and 300 degrees centigrade; after pulverizing and screening, the clay was tempered and wedged, then made into bars 10 inches by one-half inch by one-half inch. At the same time bars of the unheated clay were also made.

It was found that the bar made from the unheated clay warped very badly, and the bar made from the clay heated at 100 degrees centigrade did likewise. The bars made from the samples heated at 200 and 300 degrees centigrade showed very little warping.

The linear shrinkages were as follows:

Unheated clay	10.3 per cent.
Clay heated at 100° C	9.7 per cent.
Clay heated at 200° C	7.3 per cent.
Clay heated at 300° C	7.1 per cent.

Thus it is plain that a marked improvement was made in the shrinkage by preheating. It was noted that the clay heated at 100 de-

[1]Publications of the Univ. of Ill. A method of making possible the use of the Illinois Joint Clay. A. V. Bleininger and F. E. Layman. 1910.

[2]Owing to transfer of work, this bulletin was finally brought out by the Bureau of Standards.

grees was still sticky, while those at 200 degrees and 300 degrees had lost that characteristic property.

It will also be noted that very little decrease was made in the shrinkage between the 200 degree and 300 degree samples, hence it would be probably useless to carry the heating up to the latter figure.

They also went further with the work, making up samples in which varying per cents of the heated and raw clay were used, giving the following results:

TABLE No. 34.

Results of Preheating Treatment of Illinois Joint Clay.

Kind of Material.	Amount Tempering Water in Per cent. Dry Weight.	Drying Shrinkage in Per cent. Volume.	Burning Shrinkage in Per cent. by Volume.	Drying Loss in Per cent.	Burning Loss in Per cent.	Total Loss in Per cent.
Raw clay	33.5	41.2	21.1	32.	15.	47.
25% heated, 75% raw ..	32.0	39.1	21.	26.	9.1	35.1
50% heated, 50% raw ..	31.9	35.8	21.	15.3	11.0	26.3
75% heated, 25% raw ..	31.0	34.1	20.9	9.7	12.9	22.6
Heated at 200° C.......	29.9	29.3	20.6	0.5	4.0	4.5

From the above results it is apparent that the preheating of the clay has greatly decreased the drying shrinkage, the difference being 11.9 per cent. in volume, or nearly 4 per cent. linear shrinkage.

It will also be noted that a decrease in the burning shrinkage has also resulted from the preheating. The total volume shrinkage is decreased from 62.3 per cent. to 49.9 per cent, a difference of 12.4 per cent. The linear shrinkage has been reduced from 20.7 per cent. to 16.6 per cent. It will be noted that the shrinkage and losses decrease roughly with the increase of preheated clay. The writers also say that the sticky nature of the clay has been destroyed.

As to the cost, preheating can be carried on economically in properly constructed rotary dryers, either fired directly or making use of the waste heat from kilns. Quotations of two firms on the cost of dryers for such work were obtained. One firm recommended a rotary dryer, heated by direct firing, sixty inches in diameter and forty feet long, incased in brick. The cost of the dryer complete was $3,000, less freight.

The machine would dry fifteen tons of clay per hour, requiring eight to twelve horse power to operate, and for a material containing fifteen per cent. moisture the fuel consumption would be about 500 pounds of coal per hour. It was estimated that the cost per ton for preheating would be ten cents, including labor and depreciation.

A second firm gave the following figures: The cost of the dryer, $3,500; erection, $600.00; power required, 20 horse; fuel consumption.

60 pounds of good coal per ton of clay. The cost of drying was estimated at twelve cents per ton.

As many of the standard roofing tile clays discussed in Chapter III have rather high shrinkages, and would be improved if the same could be reduced, it was thought well, in view of the facts set forth in the above paper, to take a number of roofing tile clays of the highest drying shrinkage, and put them through the same tests used by Bleininger and Layman.

The tests, as carried out for this report, were conducted on five clays, numbers A, E, F, H and L, respectively, which were first ground to pass a 20-mesh screen. Several pounds of each were put in shallow pans and placed in the muffle of a Caulkins kiln, and the gas lit. By means of a pyrometer, the temperature was maintained for several hours at 200 degrees centigrade or above. At the end of this time the clays were taken out and cooled. It was found that they had materially changed in color, nearly all of them, regardless of the original color, assuming a light brick-red color. The clays were then tempered, and allowed to stand for forty-eight hours before wedging carefully and making into trial pieces two inches by two inches by three-fourths of an inch thick. The designation of the sample and marks 50 mm. apart were carefully stamped upon each test piece. They were weighed, and then placed in oil, and after soaking for twenty-four hours, were carefully measured for their volume in the Seger volumeter. They were then dried, reweighed, and new measurements of the shrinkage taken after complete saturation in oil. The following results were obtained:

TABLE No. 35.

Showing Differences in Linear and Volume Drying Shrinkage of Clays in Their Natural Condition, and the Same Clays Heated at 200° C.

Designation of Clay.	Volume Shrinkage of Natural Clay.	Volume Shrinkage of Dried Clay.	Difference in Favor of Dried Clay.	Linear Shrinkage of Wet Clay.	Linear Shrinkage of Dried Clay.	Difference.
A	13.47	11.63	1.84	3.94	3.70	0.24
E	12.43	11.10	1.33	3.94	4.03	0.09
F	12.96	7.55	5.41	4.03	2.44	1.59
H	19.36	12.52	6.84	6.00	3.98	2.02
L	16.96	13.61	3.34	4.88	4.52	0.36

Designation of Clay.	Calculated Linear Shrinkage of Natural Clay.	Calculated Linear Shrinkage of Dried Clay.	Difference.	Plasticity Water in Natural Clay.	Plasticity Water in Dried Clay.
A	4.71	4.04	0.67	16.01	18.19
E	4.33	3.85	0.48	16.80	19.73
F	4.52	2.58	1.94	19.08	17.18
H	6.92	4.36	1.56	19.83	20.00
L	6.01	4.76	1.25	16.67	17.26

From the foregoing table, it will be observed that the volume shrinkage has been reduced in every instance by the heating of the clay, clay H being reduced by a total of 6.84 per cent., while clay E was affected the least, having been reduced only 1.33 per cent. The linear shrinkages, with one exception (clay E), check the volume shrinkages in so far as they show a general decrease of shrinkage by the heating. The exceptional case of clay E is no doubt due to error in making the small linear measurements, because the volume shrinkage shows a small loss for this clay. It will furthermore be noted that the calculated linear shrinkages check the measured shrinkages in a general way.

The table on page 217 gives the further data obtained on the fire shrinkage of the same five clays.

It is difficult to interpret the fire shrinkages,as they fluctuate widely between clays and in the same clay itself at different temperatures with no clearly prevailing tendency. But the fire shrinkages of any clay are the least worthy of credence of any measurements obtained from the test, as they are the point where all irregularities of measurement, treatment or inherent peculiarity are sure to be lodged. The total volume shrinkages show in general what the drying shrinkages do—viz., a clear tendency to reduction by the preheating treatment and a variable degree of sensitiveness to its influence in different clays.

It was observed during the tempering of the predried clays that they had a tendency to work "short," or, in other words,after the manner of meal. Therefore, a comparison of water required to develop plasticity was made. It will be noted that the samples that were preheated have with one exception, clay F, taken more water to develop their plasticity than the clay in its raw or natural condition, which is very surprising in view of the reduction in shrinkage.

While no actual data were obtained on the rate of drying of these trials, it is firmly believed that, owing to their granular condition, they dried very easily and at a much more rapid rate than in the case of the same clays in their raw condition.

The fact that a clay like H had its volume shrinkage on heating reduced 35.33 per cent. and its linear shrinkage 33.51 per cent., or in other words over one-third of the total amount, should convince the most skeptical that there are great possibilities in this preheating treatment for some clays. The findings obtained in this work throw no new light on the work of Bleininger and Layman, except to show that their process applies to other clays than those studied by them and that it does not by any means apply to all with equal force. Some clays are evidently but little affected. Much fuller and more careful investigations on this subject are in progress in the U. S. Geological Survey laboratories at Pittsburgh, under direction of Professor Bleininger, where the cause is being earnestly sought for and the behavior of different clays at different temperatures is being studied.

TABLE No. 36.

Showing Differences in Shrinkage in Burning Between Clays Subjected to the Preheating Treatment and the Same Clays Without This Treatment.

Designation of Clay.	Temperature of Burning Expressed in Cones.	Total Per cent. Volume Shrinkage of the Clay without Preheating.	Total Per cent. Volume Shrinkage of the Clay with Preheating Treatment at 200° C.	Reduction of Total Volume Shrinkage by Preheating.	Per cent. Fire Volume Shrinkage of Clay without the Preheating Treatment.	Per cent. Fire Volume Shrinkage of Clay After Preheating Treatment.	Variation of Volume Fire Shrinkage Between Preheating and Untreated Clay
A	09	16.50	13.92	2.58	1.648	1.269	—0.379
	07	22.17	20.02	2.15	5.370	4.526	—0.844
	04	28.81	27.31	1.50	9.130	8.025	—1.105
	01	29.94	27.92	2.02	9.340	9.105	—0.235
E	09	13.41	12.88	0.53	0.424	0.688	—0.244
	07	14.58	12.04	2.54	0.138	0.855	—0.717
	04	13.56	13.09	0.47	0.859	1.220	—0.461
	01	18.51	15.15	3.46	2.890	2.490	—0.400
F	09	13.05	8.51	4.54	0.566	0.185	—0.381
	07	17.60	12.08	5.52	2.710	2.115	—0.595
	04	21.18	14.06	7.12	3.760	3.809	—0.049
	01	23.80	15.60	8.20	5.605	4.163	—1.442
H	09	20.43	13.04	7.39	0.327	0.494	—0.167
	07	21.84	15.01	6.83	0.659	1.756	—1.097
	04	23.97	21.32	2.65	3.144	1.070	—2.074
	01	27.14	20.52	6.62	4.988	4.733	—0.255
L	09	21.87	19.84	2.03	2.85	3.57	—0.72
	07	24.93	21.93	3.00	4.67	Bloated	....
	04	swelled	swelled	....	Bloated	3.910	....
	01	swelled	22.41	....	3.630	3.480	—0.150

With the above figures at hand it would seem certain that it is within the reach of the roofing tile manufacturers of the country to install and operate such preheating equipments. The results shown in the original article and those obtained from the study of actual roofing tile clays show highly desirable results in most of the clays tried.

The relatively small tonnage of material used per day by the roofing tile manufacturers, and the price obtained per ton for the finished ware, make it entirely within the scope of possibility for them to preheat their clays. It certainly would be of great advantage to those working highly shrinking clays to preheat all or part of their clay at least. By the utilization of waste heat from the cooling kilns the cost of the treatment could be reduced to a few cents per ton, even putting it within the reach of the brick manufacturer. It is beyond doubt that those who have been using rotary dryers for purely drying purposes, have often obtained something of the value of this preheating treatment without definitely recognizing it, at least for a part of the time, if not constantly. One such instance is on record, where a brick manufacturer had almost no trouble from cracking in winter when his dryer was necessary to grind the clay, but had constant trouble in summer, when the clay was dry enough to grind without the dryer being used.

Screening.—The purpose of screening is to set a limit to the maximum size of mineral particles which will be allowed to enter a piece of clay ware. As the coarsest particles in a ground mixture are also apt to be the hardest and also of different chemical composition from the general matrix of fine material which contains the plastic aluminous matter we think of as clay substance, it follows that these coarse particles are both difficult to grind finer and are the most injurious to the homogeneous character of the clay if they are not ground and made to blend well into the matrix. Particles of limestone, carbonate of iron, gypsum, pyrites, coal, etc., are all able to ruin the appearance of the product unless thoroughly disseminated by fine grinding.

Screening is therefore necessary to establish a limit beyond which particles cannot enter the clay body, except by accident. It is a very necessary part of the process of homogenization, of which grinding and tempering are the two principal steps.

The operation of screening clays is more troublesome than that of screening other dry powders, because of the sticky nature of clay grains when damp, as explained under predrying. For this reason, the actual size limit used in clay plants is often much greater than is desired by the manufacturer, because without predrying he cannot either grind or screen effectively. By thoroughly drying a clay in advance, fine grinding in the dry way becomes possible to any limit needed for the most exact homogeneity of product required for any commercial uses.

The maximum size of particles permissible in roofing tiles is probably somewhat less thån for other parallel industries like paving brick, face brick, sewer pipe, etc. In general, a screen of 8 meshes per lineal inch, or 64 holes per square inch, with the wires which make these meshes occupying about one-third of the space, represents commercial fineness for brick and pipe. That makes the diameter of a particle to pass these holes not to exceed about 0.08 inch, though 0.10 would be likely to be found due to irregularities of weaving of the wire cloth. But besides wire cloth, screening is done by perforated metal plates, with round holes or slotted holes, and latterly by piano wire screens with long slots, practically free from cross wires, so that the particles of flaky shape may, theoretically at least, pass the screen with far larger dimensions than 0.10 on one or more of their axes.

The expression "ten mesh" or "eight mesh" does not, therefore, carry a clear and unambiguous meaning of size, for the size of the wire must also be stated. Perforated metal with round holes makes a screen much slower to operate, but a much more exact standard of size.

Roofing tile clays in general are passed through from twelve to twenty mesh screens or equivalent. In one instance eighty mesh was used for a long time, but this is altogether unusual, and was also unnecessary for a product of the required grade.

Classification of Screens in Use.—In going over all the styles of screens in use, it is found that with two exceptions manufacturers are all using some form of the inclined screen, either stationary or movable.

Stationary Inclined Screens.—These consist of an inclined chute, the bottom of which is made of perforated metal or woven wire cloth, over which the pulverized clay passes by gravity. The size of the perforations and the angle at which the screen is hung governs the size of grain that will pass through it.

Should the screen be horizontal, particles the same size as the openings will pass through, but upon elevating one end of the screen so that the material attains a momentum, the particles passing through will become smaller and smaller as the angle of elevation increases.

Advantage is usually taken of this fact in constructing inclined screens, so that variations in their angle can be easily made. During the seasons of the year when the clay is damp and screening difficult the angle can be flattened to enable the material to more readily pass through. As the material becomes more dry later in the season, the screen can again be raised to its former angle. The manufacturer can thus keep up nearly his proper daily output, although this means, of course, a lowering of the standard of his wares as to homogeneity in bad weather, which is a practice full of danger to the reputation of the product. The stationary inclined screen gives much trouble through its tendency to become caked over with clay, especially when the clay is

damp. This means that the attention of some one must be given to the screen to keep it effective. Ordinarily a hoe or shovel worked backward and forward over the surface of the screen will partly keep it cleared of caked obstructions. Very often the work of keeping a screen clean is left to the dry pan feeder or some one else whose main duties are elsewhere. Visits to screens, up dusty stairs or dark ladders, are always likely to be at long intervals, for everyone is likely to dodge a disagreeable task if he can. It very often happens that one-third or one-half of the clay delivered to the screen from the grinder is being returned to the grinder as tailings because it cannot pass through the coated or clogged screen. The attendant will then make his way to the screen loft, and in desperation will attack the accumulation too vigorously, loosening large chunks of the caked dust, which slide down the screen and are likely to choke the tailings spout. This necessitates a shut-down of the pan while the obstruction is being removed.

The fixed incline screen was found in use in only one roofing title plant, the Huntington Roofing Tile Company, Huntington, W. Va. Their material, as mentioned before, is composed of two shales, one very plastic and the other very sandy. The proportion of the mixture was not obtained, but the screened clay appears to be quite high in free silica. A sandy clay is not nearly so likely to cake on a screen as a more fat, plastic one. It was also found that the mesh of the screen used here was sixteen, which is a little coarser than the average mesh used by roofing tile manufacturers. These two facts probably explain why it is possible for this firm to use this simple type of screen without prohibitive trouble.

Piano Wire Screen.—A rather recent form of inclined screen is called the "piano wire type," which has been in use for only a few years. As the name implies, the screen is made of heavy steel piano wires. These are strung parallel on a strong, substantial cast or wrought iron frame about two and one-half feet wide by six feet long. The wires are drawn to a high tension by screw tightening pins, and should be so firmly secured that they cannot slip. If this is not guarded, the screen becomes very inefficient indeed. At each end of the frame the wires are drawn over a heavy rod, which is threaded to suit the space required between the wires. By varying the pitch of these threads the mesh can be easily changed to suit the conditions under which the screen is to be used.

A threaded rod is also placed in the middle of the screen, and sometimes two are used to steady the wires and prevent them from spreading apart when pieces wedge between them. The screen is usually set or hung so that the angle can easily be changed to meet changes in the condition of the clay. A very satisfactory expedient for preserving the distance between the wires without making any superficial obstacle for the clay to lodge against or start to cake upon, is to solder strips of tin on

the lower side of the wires at intervals of a foot or so apart. The solder can be scraped smooth with the top surface of the wire very easily; it takes up but little room, and is easily repaired at any time.

The increased rigidity of the wires is very important, indeed, in preventing wedging apart and consequent irregularity of output. The claims for this style of screen are: First, it has a large screening capacity, while giving very little trouble from clogging or packing of the clays; second, it does not cost anything for power to operate it; third, it requires but very little head room to house it.

The above claims are all well founded, and without question for some classes of clay product this machine is a very valuable invention for the trade.


Fig. 62—Piano Wire Screen.

As applied to the roofing tile industry, a strong objection has been raised against it. This objection is that it is impossible to secure a close enough accuracy of sizing for roofing tiles, owing to the wires stretching and becoming loose, sagging down and allowing large grains of hard material to pass through.

Three plants were found to be using the piano wire screen with more or less success, depending on the nature of their raw material.

One plant, using a very soft, easily slaking shale, was getting very good results. The very next plant visited, which was working a very hard, sandy shale, was getting anything but good results, the surface of the tiles being rough and unsightly at close range. One of the largest plants had at one time installed two piano wire screens, and after giving them a thorough test taken them out on account of their requiring too much attention to keep the product as uniform as is desired.

The "Perfect" Screen.—This screen seems to be in most favor with the roofing tile manufacturers. It is made by the Dunlap Manufacturing Company, of Bloomington, Ill. It is a modified form of the inclined screen. The main difference is that the screening surface, composed of plates of perforated metal, is continually in motion on an endless chain.

The object of this device is to bring automatically every part of the screen surface over a rotary cleaning brush instead of depending on its being done by hand, as is the case with all stationary inclined screens. The perfect screen is made up of sectional screen plates, attached to sprocket chains on each side. These chains travel upward

on an inclined frame-work around sprocket wheels at the top, back on the lower side, etc. There are four points of attachment to each plate, two on each side. One attachment is at the forward edge of the plate and the other is at the center, permitting the plates to travel around the sprocket wheels without binding. The clay from the grinding machine is thrown onto a spreading board at the upper end of the screen. After leaving the spreading board, the clay slides down over the surface of the screen plates which are travelling in the opposite direction, or against the down-coming stream of clay. The clay, passing through the perforated plates, drops onto a floor which is between the two lines of travelling plates. The floor is more highly inclined than the screen proper, thus facilitating the delivery of the fine clay at the lower end where it falls upon the reverse side of the perforated plate. As the plate revolves around the sprocket wheel, the clay is dumped off into a bin below. The tailings flow over the lower end of the screen into a spout which returns them to the grinding machine. Curtains of loose aprons of canvas are hung down, touching the surface of the up-travelling screen plates. These retard the down flow of the clay, and have an effect similar to that of rubbing material through a screen by hand.

On the other side of the frame work is a rotating brush, held in contact by weights with the face side of the screen plates as they pass downward on their return trip. By adding more or less weight to this brush, it can be made to brush harder or easier, as the condition of the clay requires.

The screen plates in this machine are most usually of perforated metal, although piano wire plates can be furnished. In the metal plates, the perforations are usually slotted and are placed in rows herring-bone fashion, thus causing a greater resistance to the clay passing over it.

The entire screen is so hung that its angle can be changed in a very few minutes.

The rate of travel of the screen plates is quite slow, not over three or four feet per minute, so that the wear on the machine is very slight and the power used is insignificant. The screens are made in three sizes, the medium size is the one most used by the roofing tile manufacturers. This size will easily care for the clay from a single nine-foot dry pan, and screen it to the fine mesh desired for roofing tile.

In five plants, six of the above screens were found in use, the range of the meshes being eighteen at three plants and twenty at the two others. No trouble was found in obtaining a sufficient amount of screened clay of this fineness. Owing to the constantly revolving brush, the room where this screen is used is for the most part rather dusty. The sweepings are generally allowed to fall to the floor instead of being caught in a chute and returned to the pan. This latter point

is not a fault of the screen in question, but merely represents poor construction on the part of the builder. There are a number of distinct advantages in this type of screen over others.

Fig. 63—The "Perfect" Clay Screen.

Its automatic cleaning is simple, effective and cheap. It requires almost no attention, and it has a large capacity, and will screen finer clay than other inclined screens because it is always clean.

On the other hand it requires some power to operate it, though not very much. It makes a good deal of dust, and is large, and requires considerable head room. None of these objections are serious.

Centrifugal Screen.—There yet remains to describe a screen found in the plant of the Ludowici-Celadon Company, at Alfred, N. Y., which is out of the ordinary in the clay industry.

It consists of a large funnel-shaped cage or receptacle, about four feet high with a diameter of nine feet at its upper or large end. The shell of this funnel is made of perforated metal. Vertically through the center of this cone passes a shaft. At the lower end it extends through and rests in a step below the funnel. The upper end passes through a bearing and is equipped with bevel gears, to be driven by power. The conical shell is fastened to the main upright shaft by means of spiders, and hence revolves with it. The clay to be screened is fed into the center of the rapidly revolving cage. Upon striking the floor it at once begins to move up the sloping sides of the screen by centrifugal force, the fine clay being carried through the perforations while the coarser material travels on up the sides until it passes out over the top where it is caught in a trough and returned to the dry pan. The screened clay is intercepted by an exterior conical shell or casing that encircles the screen. Sliding down this floor, it enters an elevator boot where it is elevated to the storage bins.

It is claimed by the owners that this screen has for a number

of years given excellent satisfaction. In fact, the first one proved so satisfactory that the company later added a second one, though of smaller size, the latter one being only six feet in diameter at its large end.

This type of screen, possibly differing in some details, has since been taken up by the manufacturers of clay machinery and applied to other plants.

In the Alfred plant, it is somewhat unfavorably situated, being set on the second floor on a level with the clay bin, and thus requiring two elevators to serve it, one to bring clay to it and the other to carry the fine screened product up to the top of the bin near by. This is a local fault and in no wise diminishes the effectiveness of the machine itself.

Other Types of Screens.—There are many other screens in use in other clay industries, which might have been applied equally well to roofing tile manufacture. Shaking or vibrating screens, rotary or cylindrical or conical screens on a nearly horizontal axis, gyratory screens, pneumatic sizing by means of air blasts, are some of the more important. None are especially more effective than those discussed.

The screening done by the Ludowici-Celadon Company at their Chicago Heights plant is unusual, both as to method and fineness. After passing the pan, the clay is caught up by a cup elevator and carried to the third story of the building, where it is thrown onto a pair of inclined gravity screens, constructed like a letter A, having an angle or opening of about 90°. These screens are joined at the top, or apex, and are about thirty-six inches wide by eighteen feet long per side, thus giving a screening area equal to a single screen thirty-six inches by thirty-six feet.

The advantage claimed for this arrangement is that a lower building is required than if built in one single screen. There is one disadvantage however. The screened clay that falls through one end of the screen must be conveyed over to the other side in order to have it dumped in the same bin. This conveying is done by means of a belt conveyor.

The mesh of the screen was found to be one twenty-eighth of an inch, but with this extremely fine mesh set at an angle of forty-five degrees, the actual degree of fineness of the clay screened is nearer to forty or sixty mesh than twenty-eight.

It would seem next to impossible to screen the large tonnage used by this company through a screen of the above type and size and to such an extremely fine mesh, and under ordinary conditions it would be wholly so, but when the condition of the clay that goes to the screen is considered, it is not so hard to understand. The clay comes from the rotary dryer perfectly dry and so hot that after it passes the dry pan, and has been elevated and screened, it still contains so much heat that one can scarcely hold it in the open hand.

Under no other conditions would it be possible to screen so large a quantity of dry clay to so fine a mesh, which is much the finest used by any roofing tile plant in the United States.

Studying briefly the results accomplished by this fine grinding, the heretofore mixture of rocky gravel, clay and sand has been made so fine and intimately mixed that it is, roughly speaking, a definite compound. That is, it will act more nearly like a single substance than as a mixture of several independent ingredients. The most troublesome material, limestone, has been reduced to such fine grains that it has lost its power to cause popping. It still makes the body a little lighter in color, and possibly helps to form sulphate scum on the surface of the tiles if brought in contact with sulphur gases in the kiln or dryer.

While the use of glacial clay like this for roofing tile manufacture has been proved possible by this company, still it is not to be recommended, unless it be in very rare cases, in a territory where all other clays are lacking. Owing to their variable composition and the great care and expense necessary to prepare them properly, their use from an economical standpoint is to be condemned.

As a rule glacial till runs so high in lime content that it is impossible to vitrify it safely. High lime content in a clay has that peculiar and treacherous feature of causing a very short vitrification range.

So narrow is the limit between a good hard body and a vitrified one, speaking, of course, of limy clays, that the trade has not at its command a kiln permitting of regulation close enough to burn such clays to vitrification with safety.

This means that the burning of glacial clays must stop at a point well below the complete vitrification point. In other words, the body must be left porous.

Again, it is not likely that a clay of glacial origin will, with its various ingredients, burn to the good clean red so much desired for roofing tiles. This means that to obtain a good color the manufacturer must go to the expense of buying a good red burning clay elsewhere, and using it as a slip coating over the face of the glacial clay tile.

This false covering is only a makeshift, adding greatly to the cost of production, and unless the body and slip fit well, they are likely to separate and peel. Also accidental chipping of the tile discloses its light colored body beneath the slip and keeps customers irritated over trifling defects not at all visible after the tile is in position.

So, though this company deserves much credit and admiration for the way it has overcome the disadvantages of a badly selected clay, by thorough mechanical treatment, still it is under a handicap in using it.

Summing up the various screens in use at the roofing tile plants of this country, the following list is obtained:

TABLE No. 37.

Showing Various Types of Screens in Use Among Roofing Tile Plants.

Kinds of Screens.	Number Plants Using.	Number in Use.
Gravity, inclined	3	3
Piano wire, inclined	3	3
Shaking	1	1
Perfect clay screen	5	6
Centrifugal	1	2
None at all[1]	1	0

[1]Using soft clay in a wet pan.

Tempering.—Tempering means the adjustment of the water content of a clay to the forming operation which is to follow. In the dry press the amount of water used is small, and in fluid casting the amount is very large, but the same word "temper"applies to the adjustment of the dry press powder for pressing and the thickness of the slip for successful casting.

In ordinary clay working processes, depending on the use of clay of plastic or pasty consistency, tempering means the regulation of the water content so that this plastic quality may be most fully or at least sufficiently developed. This involves not merely the adding the water, but in securing its even distribution over and among all the particles of the clay.

The modern conception of a plastic clay is that of a very stiff fluid, in which every grain of solid matter is surrounded by a liquid film or envelope, so that the particles are virtually in a state of fluid suspension. This has been discussed in Chapter III in connection with shrinkage and water of plasticity.

It is evident that to get a piece of clay into such perfect temper that the preceding conception becomes true or approximately true, calls for a very complete disintegration of the solid particles, so that they may readily assume the new relation towards each other under the influence of water.

The ease with which different clays take up water and assume this state of fluid suspension, or plasticity, varies very widely. The chief causes of variations are physical. They do not center so much in the proportions of the "clay substance" or plastic elements vs. the sand or anti-plastic elements as was formerly believed. It has been shown that many rocks, powdered finely, yield more or less plasticity, and that

only a small amount of plastic clay may convert a large amount of otherwise anti-plastic matter into workable shape. The purest clays are often of low plasticity.

The important factors affecting the plasticity of clays are those of pressure, consolidation, heat and infiltration of hardening or cementing substances, like bitumen, ferric hydroxide, or carbonate of lime. In the clays of the present time or Pleistocene geological period, like river flood-plain clays, glacial till and lake-bed clays, consolidation by pressure is at its minimum. These clays are all superficial and have never been covered by deep deposits or great weight. They are constantly being opened up by the infiltration of surface water, and frost, and vegetation. Such clays are always easily brought to as much plasticity as their mineral make-up permits. They temper easily.

Clays which had their origin in geological periods preceding the Tertiary are always much hardened by the vicissitudes of heat and pressure to which they have at various times in their long existence been subjected. These clays are generally hard and rocklike unless softened superficially by weathering. Tempering such clay means breaking down the close, dense structure given by pressure and heat, and oftentimes dissolving out or loosening up the hardening solutions which have permeated the masses of mineral grains and filled the voids with a hard cementing filler.

Clays which had their origin in Tertiary or later periods, down to the Pleistocene or present period, are as a rule much less hardened or fossilized, and can as a rule be made plastic with comparative ease, though they are by no means like the present clay, and locally have often been hardened as completely as the carboniferous or Devonian clays.

Whatever the structure, and no matter how great the hardening produced by age or pressure or chemical infiltrations, it is possible to restore the plasticity of a clay by mechanical treatment, provided the plastic elements have not been destroyed by heat. Clay, when burnt, can never be made plastic again, and in nature temperatures of far less than red heat have so altered the clay minerals that their capacity to assume the plastic state is destroyed. Slates, for instance, are, mineralogically, exactly like shales, except that they have lost three or four per cent. of their chemically combined water, and are non-plastic in consequence. This change was due to heat far below redness.

From the foregoing it is evident that the amount of mechanical work to be expended in getting clays into the same physical condition of plasticity is sure to vary greatly. With some it merely means stirring up with a little water—the old-fashioned vertical horse pug mill used on soft mud hand brick yards; or still more elementary, the shallow soak pits, and the tramping of the clay with the bare feet of laborers, as is still done in Mexican roofing-tile yards, amply sufficed. With

others an intense stirring, under pressure, is needed, as is given in the better class of pug mills. With others, nothing less than long-continued grinding in the presence of water, under heavy mullers, will succeed in breaking down the rock structure of the fossilized clay.

In general there are only two mechanical methods available—pugging vs. wet grinding. The old-fashioned, primitive foot-tramping cannot be considered as commercially possible today in a civilized country.

Pug Mills.—Their general features are so well understood that they need not be described. There are many variations in structure, which are of benefit or otherwise, and of these it is necessary to speak. The dimensions run from six to twenty feet in length and from two and one-half to four feet in diameter for horizontal mills. Vertical mills are seldom used today outside of the pottery industry. The pug shaft is carried at the outlet end by a simple bearing, while at the inlet end provision must be made to not only carry the shaft but at the same time to provide for the heavy end-thrust produced by the work of moving the clay forward and forcing it out through a limited aperture. This is accomplished in the more simple mills by having the boxing cast with one end closed. This boxing, of course, must be very securely held in position, hence it is usually made a part of the rear frame of the machine. The cap or end of the boxing is turned out true and smooth, then a bronze disc of the same diameter as the shaft is slipped into the bearing. The end of the shaft now is brought into contact with the bronze disc. As a rule the entire bearing runs in oil in order to reduce the friction as much as possible and keep the bearing from heating.

Pug mills are made with single shafts like that just described, and double shafts revolving toward each other.

At the outset it should be understood that the work of a pug mill is not that of grinding a clay, but only of mixing and stirring it. If given a clay with only a slightly hardened structure and slightly latent plasticity, it is possible by means of a single shaft pug mill to develop the plasticity sufficiently for most clay working purposes; but should the clay be a little more hardened, it would be better to use the double shaft mill, or possibly a very long single shaft mill.

The double shaft mill, while not giving twice the pugging action of the single mill, has a much greater capacity, thus making it possible to hold the clay under the action of the stirring knives much longer. Also by using a less number of propelling knives, or knives of a lower pitch with an increase of simple cutting and stirring blades, it is possible to regulate the passage of the clay through the pug mill until it has been throughly mixed.

Pug mills are also built open top and closed top, the difference being that the pressure applied to the clay in mixing and cutting it by the knives is limited. The clay is free to move upward, and thus relieve the pressure. But with mills of closed top the delivery of the clay be-

comes like that of an auger machine, and uses a large amount of power and rubs the clay and water together so much the more intimately.

No pug mill exercises a grinding effect on a clay. Particles of a single mineral are rarely if ever reduced in size by pugging. Agglomerations of particles of minerals, when not held together by some cementing material, may soften enough by water to come apart under the stirring action of the pug mill, but if they are at all hard or consolidated, they will not.

The pug mill is fit, therefore, for tempering unconsolidated or recent clays of readily plastic character. It is out of place with clays of difficultly plastic nature.

It is possible to use pug mills alone with no grinding machinery whatever in the case of some soft alluvial and glacial clays. Also, it has been found that many clays, by dry grinding and careful sizing of grains to exclude all coarse matter, will develop a moderate plasticity by pugging sufficient for stiff mud manufacture. Thus pug mills are in use in hundreds of plants merely as stirring machines, the dry pan breaking up the rock structure and producing a powder, the screen keeping the maximum coarseness under control, and the pug mill mixing the powder with water. Wherever this process gives a sufficient plasticity it should be used. It is cheaper, easier, simpler in every way than the wet grinding. But it will not do the work of wet grinding in dealing with difficult clays, and should never be expected to.

Wet Grinding.—The use of the wet pan as a preliminary grinder, beginning with the crude clay direct from the pit, has been briefly discussed at the proper place. The use of the wet pan as a tempering machine, with grinding thrown in incidentally, requires a little different construction and radically different operation.

Wet pans for tempering previously ground and screened clay use, generally, mullers varying from three to eight inches in face, while initial grinders usually have mullers with from ten to eighteen inch face. The crushing action is magnified in the latter, the cutting and mixing action in the narrower wheels. The weight of the muller is not necessarily less, for it is very common to see wet pan mullers with extra large hubs, which are added for their weight, it being desired to have the mullers cut through the mass of clay, and crush any particles that may be caught between them and the pan floor. The scrapers are also set differently, and are of different size, being designed as much to stir the mass as to direct it under the wheels. The use of large plows or scrapers becomes difficult with very plastic clays, for it requires excessive power to drive the pan, which is hard to drive in any case.

The pan is most usually located on the ground floor, immediately below the bin of screened clay. A tube of wood or iron, provided with a valve, or cut-off slide, leads down from the clay-storage bin to within two or three feet of the pan floor. The operation of a pan is about

as follows: The pan being run empty, the attendant opens the valve in the clay spout, and at the same time opens the water valve, letting a stream of water run into the pan. Only ten or twenty seconds are required to introduce a charge of from 600 to 1,000 pounds of ground clay and from 150 to 200 pounds of water. The stream of clay is then stopped, but the water is continued until the clay apparently becomes too soft and too sticky to use. As the grinding progresses however, this apparent excess of water soon soaks in and more water must probably be added. If the grinding is continued a minute or so extra, additions of water must be let in from time to time, the excess being soon taken up by the grains of clay, as the subdivision proceeds. The original grains, if hard, would require but little water to wet their surface, but the finer they are ground, the more water will be needed to secure the usual apparent dampness of the same. When the clay is tempered to the proper degree, determined by the touch or sense of feel of the operator, it is emptied out as speedily as possible. The time consumed in tempering a charge varies from two to four minutes usually, three minutes is a fair average in all the plants in which this operation has been timed. Of course, with some hard clays, or in an industry consuming small amounts of clay only, the time per panful will be increased.

Unloading is done by a semi-mechanical, hand-actuated shovel in almost every plant where wet pans are used. A large shovel, pivoted to the frame of the pan on a ball and socket joint, or equivalent, is lowered into the revolving pan, against the direction of motion. The clay in its travel with the pan, rushes up the inclined plane of this shovel until it will hold no more. The amounts held are seventy-five to one hundred pounds at a time. The operator then raises the loaded shovel by bearing down on the handle, swings it over the rim of the pan and dumps the load onto a conveyor or elevator to be carried to the forming machinery. Automatic unloaders of many types have been made and used successfully. Plows; scrapers, revolving buckets, mechanically driven shovels, pans with sectional rims, discharging by centrifugal force, etc., have been tried—all successfully. The problem is not difficult, mechanically.

The fact remains that the old hand method still hangs on, and is set up by many as the great obstacle to the use of the wet pan.

Operation of Wet Pan.—The wet pan gives the most thorough tempering that it is possible to give clay. The grinding action is a very important feature, especially with hard, gritty clays. The handling of such materials in a pug mill is either impossible or requires the addition of a soft plastic clay to help it out or a long-aging period to permit softening to take place in order to make perfect ware. With the wet pan the same hard clay can in a few minutes produce as much

or more plasticity than could be developed by a pug mill treatment with unlimited time.

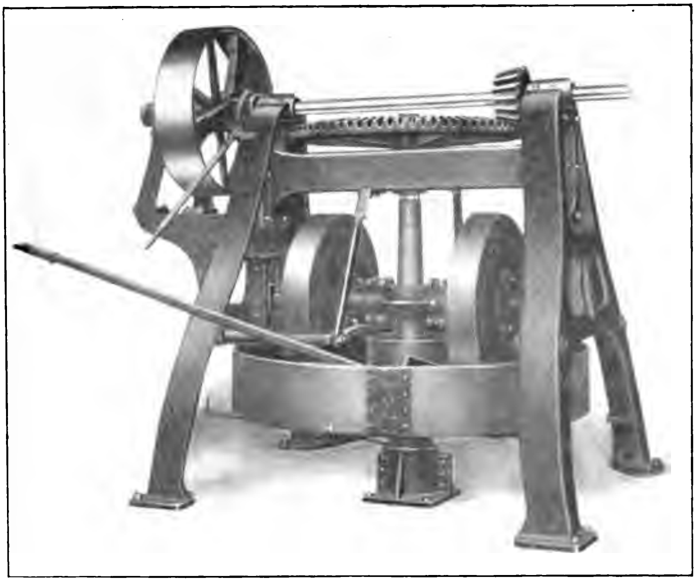


Fig. 64—Wet Pan with Shovel.

Should it be advantageous to mix two kinds of clays, the wet pan will do the work in a most satisfactory manner. The clays are actually blended until they form a new material, different from either of the two that were originally added to the machine in color and properties of burning. On the same class of work, the pug mill will only stir the two clays together, but will not in any way grind them one into the other as the wet pan would, and the color of the mixture is almost always specky, showing separate grains of both clays still maintaining their identity.

While the wet pan gives very excellent work as a tempering machine it has some objectionable points. Among them are the following:

First. Its cost of installation being about twice that of a pug mill, viz., $800 to $1,000.

Second. Its consumption of power. In most clays it requires two wet pans to prepare the clay for one auger machine making roofing tile, and if brick are to be made, three or four wet pans would be needed for a moderate auger-machine output. The actual horse-power used varies enormously with the clay, the charge tempered, the consistency or wetness desired, etc. But it is never low and probably runs from twenty-five to forty horse-power on the average, when it has a charge grinding. While unloading and recharging, the power consumption

drops and rises again, so that about one-third of the time is lighter duty and two-thirds heavy duty.

Third. The clay is tempered in batches, and even with the utmost care, it is impossible to always get each batch to the same temper. With some clays it will be found that they will absorb water so fast that it will be impossible to empty the pan quick enough to have the last of the batch of the same temper as the first. This means that the clay will go to the forming machinery in an uneven condition, giving more or less trouble, such as uneven flow through the dies and a variable shrinkage.

Fourth. The class of men required to operate them are hard to secure. They not only require a man with a keen sense of feeling and good judgment, but one of good physique also. Very often these two requirements cannot be found in the same person. It often happens that a man of light weight can determine the proper temper of the clay to a nicety, but will lack the necessary strength to operate the shovel continuously. The trouble is within the reach of mechanical methods however; where unloading devices are seriously desired, they will be found.

Fifth. The irregular load of a wet pan is hard on an engine. When two pans are in the same shop this usually regulates itself, as one is discharging and filling when the other is grinding.

While the wet pan has these bad features, it will be noted that they are largely of a mechanical nature. No fault can be found with the quality of work done by the wet pan, except as to possible variability of temper. This variability is also susceptible to mechanical regulation, by using weighing or measuring boxes for clay and water, instead of charging purely by judgment. The condition of the clay, day by day and hour by hour, would require adjustment in the quantity of water added per standard charge of clay, but this could easily be changed as found necessary and each consecutive charge of the pan would then vary only as the clay itself varied in initial water content.

In the preparation of roofing tile clays, too much stress cannot be placed upon the advisability of having the clay thoroughly prepared. Good tiles cannot be made from insufficiently tempered clays. In the case of soft clays, like alluvial or glacial deposits, it is possible to develop their plasticity by pug mill treatment without storing the clay in bins to age for several days. In the case of the fossil clays, like shales and fire clays, it will be found that only in the softer varieties can the tempering or pugging be satisfactorily accomplished by the pug mill.

Should the pug mill be used, it will be found in nearly all cases advisable to use the double shaft style, and then age the clay for a period depending on the hardness and other qualities of the clay or shale in hand.

TABLE No. 38.

Classification of Methods of Tempering at the Various Roofing Tile Plants of the United States.

Quality of Material to be Tempered.	Rolls and Pug Mill.	Pug Mill.	Wet Pan.	Both Pug Mill and Wet Pan.	Aging.
Shales	....	....	1 plant	....	No.
Shales	....	....	....	1 plant	No.
Shales	....	5 plants	....	....	No.
Shales	....	2 plants	....	....	Yes.
Soft Clays	....	2 plants	....	....	Yes.
Soft Clays	....	....	....	1 plant	No.
Soft Clays	1 plant	....	....	....	Yes.

From the above table it will be seen that of the nine roofing tile plants using shales, only one is using wet pans exclusively, one other plant has both pug mills and pans in use, and seven plants are using the pug mills exclusively for tempering. It will also be noted that in only two plants using shale is aging of the clay being practiced. Of the soft clays used in the four plants, three are being prepared by pug mill treatment followed by aging. In the fourth plant, while the clay is not aged it is given a possible equivalent for aging, by first running the soft clay through a wet pan and then through a pug mill, before entering a combined pug mill auger machine for forming the clay bar.

It can be seen at a glance that the plants using soft clays are the ones giving the best preparation, while the plants working shales, a material that is slow to temper, are using the least pains to properly prepare their body.

Far more trouble in roofing tile manufacture is due to improper tempering of clays than is generally thought. The improper flow of the clay through dies, resulting in warped and checked tiles in the dryer and kiln, is one result. It will also be found that most shale clays which pass direct from the pug mill to the auger machine, or other forming machinery, will have a tendency to form a rough bar, with corner or side checks. This is due to the weakness or lack of tensile strength of the granular clay, the coarse grains of which act as so much non-plastic material.

Where tiles are made from clays direct from the pugging machinery, the harder grains generally will not have slaked or softened down in the limited time available since the tempering began. These grains subsequently soften in the dryer under the influence of time and heat. before the water is expelled. When they do soften, they not infrequently cause changes of volume leading to cracks, warping, pimples and similar troubles. Where no outward signs of disarrangement are visible, it is possible that the tiles will suffer distortion in the kiln as a

result of their defective preparation. Now had these same clays been prepared in a wet pan, using hot water for tempering, or had it been tempered in a pug mill with hot water, and then stored in bins to age, allowing the granular particles to disintegrate before being manufactured into tile, it is believed that less loss in the kiln and dryer would have been the result.

It is also believed that while the wet pan has some objectionable features, its use should be much more general in the roofing tile industry. The amount of clay used is relatively small and the price for the finished ware is relatively high when compared to brick, so that it is possible for the roofing tile manufacturer to prepare his clay better than in some of the other industries.

Aging Clays in Connection with the Tempering Process —The method is most popular and most likely to be used is the pug mill treatment. This, however, should be done in the best possible manner. To properly prepare clay by pug mill treatment, no better machine can be recommended than a combined double shaft pug mill auger machine. The only machine of this type found in use was that of the J. D. Fate Co., Plymouth, Ohio. Of the fourteen plants working in 1908, nine of them were using this company's pugging machinery. The clay should first of all be ground to eighteen mesh or finer, and when fed to the pug mill should be treated with hot water, in slight excess of that needed to produce the proper temper for working. As the clay is worked along by the blades or knives of the pug mill, each particle becomes wet in the hot water; as the clay passes from the end of the double pug mill, it is fed into the auger machine part of the mill. Here it is compressed and packed into a dense mass by the time it is expressed from the die. By a suitable cutter, it should be cut into blocks of convenient size for handling and carried by conveyors to the storage or aging bins to go through a sweating process lasting from two or three days to a month. The time will depend on the nature of the material in hand. Some clays will slake in one-tenth the time of others. Some will never slake at all, and for such nothing but severe grinding treatment can be done.

It cannot be denied that aging clay increases the cost of production if the process stops with placing the ware on the drying racks, but if the per cent. of the perfect tiles brought out of the kilns is increased by aging, then the work is justifiable.

Among the foreign manufacturers, especially the Germans, the aging of clay is considered important. Nearly every plant has its "sumps," or damp cellar. The cost of labor does not stand so much in the way there as with our manufacturers, but where the European nations have cheaper labor with which to do their work, the American manufacturer has the advantage in more readily securing mechanical assistance. Such assistance could be secured in cheapening the cost of aging roofing tile clays.

Ordinarily, the German roofing tile manufacturer will elevate his clay by inclined track to the second or third story of his building, from whence it passes through sets of rolls, one after another, until it lands either on the ground floor or basement, where it is packed away in brick rooms or bins. After remaining in these "sumps" the proper length of time, it is spaded out into small cars, elevated a second time to the upper stories of the building to again pass through rolls and pug mills before entering the final machinery for shaping.

It is not at all improbable that in this exhaustive treatment lies the secret of the durability of the porous tile of the foreign countries. The average Anerican roofing tile manufacturer would say at once that he could not afford to handle and rehandle his clay as his German neighbor does; but if it pays the German, with his low selling price for tile, it would unquestionably prove equally profitable in this country, where better prices are received. The extra money spent to age and better prepare the clay would be more than offset by the fact that it would be found unnecessary to burn the tile so hard to make them frost-proof. The majority of American roofing tile plants are burning their tile to such a high degree of vitrification that great loss occurs in the kiln. Whether this is necessary or not, it is certain that shale clays, especially the harder ones, have often given trouble from frost if not burnt until practically vitreous. It is believed that should these same shale clays be better prepared, complete vitrification would not be found necessary to produce ware of good resisting qualities.

Observations on the arrangements for aging the clay in the various American roofing tile plants showed them to be generally very meager, and inadequate. Usually, nothing more was done than to pile up stacks of clay in the vicinity of the pug mill. In a few cases some burlap was thrown over the top of the pile and wetted down from time to time, but most often the clay was unprotected, and dust from the dry pan was found settling on the surface, assisting to absorb the water from the rapidly drying surface.

To carry out aging properly, cellars or chambers should be provided, into which the clay can be delivered by belt. These chambers should be shut up or made reasonably tight, and water should be available for wetting down the floors, walls and clay coverings from time to time in order to keep the air saturated at all times. This would permit the clay to retain its moisture rather than giving it up to the air.

Without question, the best tempering of clay in this country for roofing tiles was seen at the plant of the Ludowici-Celadon Company, at Ludowici, Ga. The method employed at this plant has in part been discussed elsewhere, but will be restated. The clay, upon being dumped from the bank cars into a hopper, is fed through a pair of large rolls, which squeeze and crush the lumps. It then passes into the combined pug-mill auger-machine of the J. D. Fate Company, where it is thor-

oughly mixed and worked by the double pugging arrangement before being passed into the auger, where it is compressed and expressed in column form, like the bar used in side-cut brick making. This bar is cut into blocks of convenient size for handling, which are carried by conveyors to open-top storage bins where the blocks are unloaded by hand and packed tightly in the bins. It remains here a week, and is

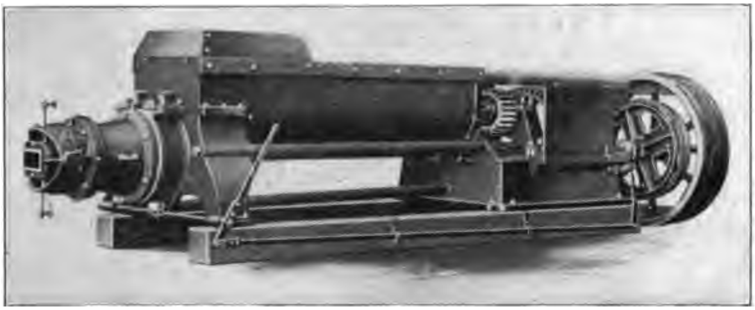


Fig. 65—Combined Pug Mill and Auger Machine, as built by the J. D. Fate Co.

then spaded out, loaded onto a second conveyor, which takes it to another pair of rolls similar to the first except that they are set nearer together. The clay exudes from this second set of rolls in very thin sheets, being scarcely thicker than blotting paper. From these rolls the clay falls into a second Fate combined pug-mill and auger-machine, where it is thoroughly reworked and expressed in blank forms ready to be fed into the roofing tile presses.

It should be borne in mind that the above treatment is given to an unconsolidated clay that is by nature extremely plastic. The preparation given it is not to develop more plasticity, but to bring the clay to its best condition for density and for toughness and for flowing through dies—in short, to make the soundest, solidest tiles possible.

If this company finds it justifiable to prepare a plastic alluvial clay in this exceedingly thorough manner, it should prove a fruitful topic for thought with some of the other manufacturers who are making tiles from comparatively plastic shales.

Scumming or Efflorescence of Roofing Tile Clays.—It is well known that many roofing tiles develop a scum, or white efflorescence, either in the drying or the burning, and occasionally after they are placed in position on the roof.

This scum, or efflorescence, is due to the presence of salts in the clay, shown by repeated chemical analysis to be chiefly the sulphates of lime and magnesia, and less frequently sulphates of iron alumina and the alkalies. Other salts, such as chlorides, nitrates or organic acid salts, may also be present and form scums.

Nearly all common clays and shales contain or have contained sulphur in the form of iron pyrites, and frequently in addition the carbonate of lime and magnesia.

When a clay containing the above minerals is exposed to the action of the air and moisture, the pyrites oxidizes to sulphate of iron and free sulphuric acid. The sulphate of iron, and especially the sulphuric acid, reacts with any of the carbonate minerals that may be present, forming sulphates, like gypsum, epsom salts, etc. Also, other minerals are likely to be decomposed, though less readily than carbonates, yielding salts of alumina, the alkalies, etc. If the clay has not been exposed to the action of the air—that is, not weathered—the pyrites is likely to remain unoxidized during working, and hence relatively harmless, though still undesirable. The other minerals will, therefore, probably remain innocuous, though some clays contain already in themselves water-soluble minerals like gypsum, already formed when the clay was laid down. Such clays are usually too impure to work, and hence do not come into serious consideration. Carbonate of lime or magnesium may be present in large quantities; sometimes in glacial and alluvial clays they may be present in large fragments or as gravel. These carbonates are not easily soluble in pure water. They do not give so much trouble, but with carbonated water they are more soluble. In wares of thin section, like roofing tiles, these carbonates may be changed to sulphates by the action of the sulphur gases of the kilns. Unless the tiles be so hard burned or vitrified as to prevent water absorption, it may be found that after they are on the roof they will show signs of whitewash, due to the rainwater soaking into them and dissolving out these sulphates and then depositing them on the tile's surface as the water evaporates.

The soft, or bituminous, coal used for burning contains sulphur in the form of iron pyrites as well as organic sulphur compounds. When such coals are burned, the iron sulphide gives off gaseous sulphur dioxide or trioxide. These gases pass through the kiln, combining with any water or moisture to form sulphurous or sulphuric acids, which, as stated above, readily forms sulphates from the carbonates.

It is for this reason that often when tile are set wet they will come from the kiln coated with white. The damp tiles very easily absorb the sulphur gases, forming acids, which in turn form soluble salts or dissolve materials not otherwise soluble, and then, as the heat increases, the acid is driven off, leaving the dissolved salts behind on the surface of the tile.

There is still another source from which efflorescence may arise, viz., the water used for tempering. Water taken from wells and streams is more or less impregnated with salts dissolved in it. These salts are usually the bicarbonates of lime and magnesium, and also the sulphates of the same bases. If in large enough amounts, these salts will cause

whitewash, the same as though they had originally been in the clay. Salts may also be obtained from the mortar used in bedding the tiles, though this is not a common thing in the American system of laying.

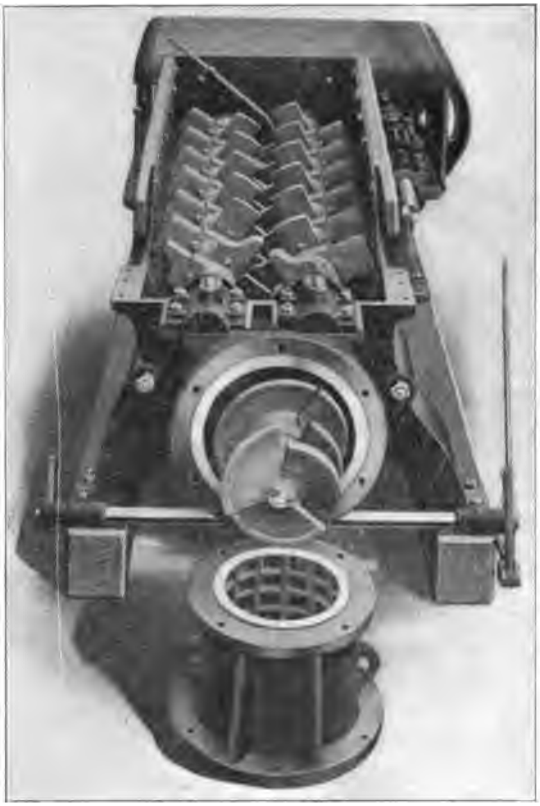


Fig. 65-A—Combined Double-Shaft Pug Mill and Auger Machine.

Prevention of Efflorescence. — To cure a disease it is necessary to remove the cause, and the same principle applies to efflorescence.

In the latter case, we can apply the following methods:

First. Free the clay entirely from soluble salts, by washing it thoroughly. This is theoretically possible, but practically is too expensive. Water of sufficient purity is seldom attainable.

Second. Use the clay straight from the pit before the salts have a chance to form through the influence of weathering of iron pyrites. This is generally feasible, though disadvantageous in other respects.

Third. Prevent the formation of the salts by rapid drying and water smoking.

Fourth. Avoid sulphury fuels for drying or burning.

Fifth. Change the soluble salts to insoluble ones by chemical additions to the clay or the water.

Sixth. Paint the surface of wares with tar, or some similar agent, which will not evaporate or soak in, but will drive the water to escape from the untreated portion of the surface. When the tar burns off later, no scum is found where it was.

Seventh. Application of a coating which on drying peels off in flakes, carrying the collected salts with it. This method has never been used in this country, but was patented in Germany about eight years ago.

Taking up the first method, that of washing the clay or weathering it. The white-washing salts are all soluble or can be made so by weathering. The action though, is slow, and to be properly done, the clay must be spread in thin layers upon a sloping floor, either natural or prepared, so that as the rains wash through the clay dissolving the salts they may be drained away. Otherwise salts will accumulate in concentrated form at the bottom of the weathering pile. This method requires the rehandling of the clay, and as the work to be well done must be extended over a long period of time, it becomes necessary to have extensive weathering areas or floors. Hence in a practical way, this method is too expensive and should not be considered.

The second method. While extensive weathering will prevent white wash, a short period of weathering is very likely to cause the same in a clay that might otherwise be free. As stated before, the sulphates which are soluble are chiefly the results of the weathering of iron pyrites. Hence by working a clay containing pyrites, into ware as quickly as possible, it is often possible to prevent these salts from being formed.

The third method, that of rapid drying and burning, depends largely on getting the tempering water out of the tiles as speedily as possible. Just why the same quantity of water will cause a scum on the surface of a clay if evaporated slowly, in a steamy atmosphere, and will not if the drying be pushed vigorously, is not yet fully understood. It is an unquestionable fact nevertheless. The clay seems to act like a filter, holding back the salts in quick drying, but if time is permitted, they work through the filter and reach the outside at last. It is unquestionably largely due to causes *two* and *three*, that many of the roofing tile plants are troubled with scum at certain times and not at others. Especially is this so in the winter months, when the drying is more likely to proceed slower than during the summer. Also it is usual to draw the material largely from storage piles which have been air weathering from the previous summer, and this air weathered clay often causes scumming, which is avoided when working direct from the pit.

Fifth method. This method is the one most universally used, not only in the roofing tile plants, but in all other branches of the clay industries. Without going into detail as to the various agents that

might be used for the above reaction, it will suffice to say that the compound used must necessarily be cheap and easily handled. So far, some salts of the element barium have been found the most effective, especially the carbonate and chloride. More often the former is used.

When either of these salts is added to a clay containing soluble sulphates, one of the following reactions takes place.

$$Ba\,CO_3 + Ca\,SO_4 = Ba\,SO_4 + Ca\,CO_3$$
$$Ba\,Cl_2 + Ca\,SO_4 = Ba\,SO_4 + Ca\,Cl_2$$

Thus, barium sulphate is formed in either case, which is one of the most insoluble compounds known. Hence, when the calcium or magnesium sulphates have been acted upon by the barium carbonate two insoluble compounds are formed, both inert to the action of the tempering water or kiln gases. No scum can form, as nothing remains soluble. Barium carbonate in itself is only slightly soluble. In order to get it to react with the sulphates, it is necessary to have the two in actual contact. The problem thus arises how to best accomplish this end. In most plants, it is customary to add the barium at the wet pan or pug mill, at the time the water is added for tempering. For some clays low in soluble salts this method will do, but frequently with pug mill treatment it is not sufficient. In some plants they add the barium at the dry pan, thus getting a better mixture. In others, large blunging tanks into which the tempering water and barium are added are provided for, and the latter is kept in suspension by revolving paddles. The barium introduced in suspension in the tempering water is more apt to become closely in touch with the sulphates than if added dry.

While the chloride of barium is easily soluble, its use is not to be recommended, because any excess above that required to counteract the sulphates may be drawn to the surface and itself form a scum by the evaporating water. Also, the product of its reaction with lime salts is chloride of calcium, which is very soluble, and forms a scum, though not so permanent or troublesome a one as the sulphates. Then too, any soluble form of barium is an active poison, so that the use of the chloride should be attended with much care.

By weight, 172 parts of calcium sulphate requires 197 parts of barium carbonate, or in other words, for 1 part of the sulphate it will require 1.15 parts of the barium carbonate to counteract it.

Taking for example, a clay containing 0.1 per cent. calcium sulphate. Owing to inability to get the barium evenly distributed throughout the mass of clay, it has been found from experience, that there should be added a large excess over the theoretical quantity, in the neighborhood of ten times as much barium carbonate as is theoretically required. Thus with barium carbonate costing two and one-half cents per pound, and a clay containing 0.1 per cent. calcium sul-

phate, there would be required for a square of tiles, weighing 1,000 pounds, approximately twelve pounds of barium, costing thirty cents. While this would be an added expense, its use would not be prohibitory.

It very frequently happens that the large hand-made ware about a roofing tile plant is the only class that gives trouble from white wash. In the light of what has been written in the last few pages, it will be easy to understand why this is so. The tile made by machinery passes directly into the dryer and is very quickly dried, while the thick, heavy ware made by hand is allowed to stand for days, in order to dry slowly. Then upon going to the kiln, it is much more likely to be damp than the tiles. So that the slow drying combined with the possible kiln dampness is very apt to promote the formation of soluble salts in and on the hand-made ware, where the regular tile will escape it.

It has been the custom in a few of our plants, and more frequently in the old world, to coat or paint the newly made terra cotta pieces with tar or oil, on the exposed or face side. This coating of tar or oil will cause the water that is in the piece to evaporate from the inner or opposite side, thus depositing the greater part of the salts where they will not be objectionable. Any salts that have formed under the tar or oil, will very likely be broken up or reduced as the tar burns off, liberating the sulphur which passes off with the kiln gases. This method of preventing scum on special made pieces was used by the writer in 1899 with remarkable success.

There is also a custom among a very few plants at the present time to add a small per cent. of black oxide of manganese with the barium carbonate, it being claimed by those using this method that the manganese helps very materially in preventing the scum. It is possible that the manganese acts favorably in hiding the scum. At least, where used it was impossible to find a white washed tile. But no chemical ground for this practice can be discovered, and it is probably unnecessary and without result.

CHAPTER V.

THE MANUFACTURE OR FORMING OF ROOFING TILE.

In the preceding chapters, the selection of the clay and its preparation in the form of a stiff mud or plastic paste have been discussed. The fashioning of this plastic paste into the various simple and complicated shapes found in the roofing tile industry forms the subject of this chapter.

As in the manufacture of nearly all other clay products, there are a number of different methods of attaining approximately the same end, and also, the same method may be applied to producing a variety of different products. Exact classification is therefore difficult.

MECHANICAL APPARATUS FOR ROOFING TILE MANUFACTURE.

Roofing tiles are produced by at least four different methods:

First—By exclusively hand molding. This is the simple archaic process which has originated in every part of the world when the use of roofing tile was first attempted. It is not to be considered as a serious manufacturing method to-day, especially in this country. It can still be found in use, however, in Mexico and many countries where labor is cheap and ignorant and machinery expensive.

Second—By use of a hand power press or machine.

Third—By use of a mechanically driven power press.

Fourth—By forcing out the clay through a die of proper cross section, and cutting up the resultant column or bar into tiles of proper length.

Neglecting the small and unimportant output made by hand or by hand presses, we may say that the roofing tiles of to-day, in America at least, are made either by the fourth or a combination of the fourth and third methods given above. The fourth method is applicable to the production as finished tiles only of simple forms of the shingle, Spanish and interlocking patterns. The true interlocking tiles cannot be made by this method. As they are the most important varieties of roofing tiles, it follows that the combination method of manufacture, by forming the clay into clots or blanks, of the proper size, shape and weight by means of the flow die process, followed by their pressing into finished roofing tiles by some form of power press, is the most common and must important process of manufacture to-day. There are, therefore, two important types of machinery to consider: viz. first, the flow die machines, which may produce a finished product by themselves

alone, but are most widely used as preparatory machines to form blanks; and second, the power presses, which cannot economically be employed except when fed with prepared blanks, but which are necessary as the final step in all but the simplest forms or designs of roofing tiles.

FLOW DIE MACHINES.

Whenever plastic clay is subjected to pressure, it tends to obey the laws of a fluid, by transmitting its pressure equally to all parts of the mass, and by escaping by flow, through any and all orifices which may be accessible. Plastic clay is far from being a perfect fluid, but under high pressures it is capable of flowing very much like a fluid would, and through very small aperatures. Whenever the pressure ceases the parallel also ceases, for the erstwhile fluid at once stiffens to a more or less solid mass, retaining the form received during its period of flow.

There are two types of flow-die machines, differing in the mode of applying the pressure to the clay: first, the plunger or piston machines, and second, screw or auger machines. The former comprise several varieties, while the latter are to a much larger degree true to one single type.

Plunger or Piston Machines.—There are several types of these machines. The direct acting, where a piston is made to press the clay ahead of it, by means of steam, compressed air, or water or oil under pressure, and the indirect, where the piston is actuated by some form of mechanical gearing, cams, cranks, levers, screws, etc. These various devices have been evolved in connection with the sewer pipe and brick industry chiefly, and only one plunger machine was found in use in the American roofing tile plants. This was at the works of the Cincinnati Roofing Tile and Terra Cotta Co., at Winton Place near Cincinnati. In this machine, the clay is pushed out by a movable head or piston working back and forth in a rectangular chamber. The head is moved by an eccentric or crank shaft and connecting rod.

On the back stroke, or as the head is drawn back to its stopping point, an opening into the clay chamber is disclosed. Into this opening a quantity of clay is fed, and as the plunger head comes forward it pushes the clay ahead of it. After a sufficient amount has been added to fill the front of the chamber, the clay will be seen to issue from the die in spurts, corresponding to each forward movement of the plunger. Naturally the flow cannot be continuous, as in the case of the screw or auger machine, but is always intermittent in a reciprocating machine. The length of flow—or, in other words, the distance that the column will issue from the die at a stroke—will depend on the amount of clay fed into the machine at each stroke by the feeder. It is only natural to expect the results from a mechanically geared plunger machine to be variable and unsatisfactory. After each stroke of the plunger the issue comes to a full stop. Then, as the new charge packs, consolidates

and comes forward, the column shoots out of the die at a high speed, diminishing as the plunger reaches the most forward point in its stroke. The irregular speed means that the clay has very little time to adjust itself to the conditions existing in the die. Then, further, there is always more or less wastage, due to the fact that the feeder is unable to adjust the feeding so that an equal length is issued each time. Hence, in order to be sure to have sufficient clay bar issue to make the proper length for a tile, the extra clay must be added each time. This extra material is cut off as waste, and must be rehandled to get it back to the machine again. The difficulty of regular feeding and the ill effects of irregular feeding are both apparent. It would seem as if some preliminary machine to pack the clay into a compact mass, of which a uniform quantity could be fed with each stroke, would materially help the performance of the geared plunger machine.

In this connection a small auger machine, through which the clay could be run in a continuous column, has been suggested. By means of a simple cutter, this column could be cut into lengths which would contain just the necessary amount of clay for each tile. By having the auger and cutter located above the plunger, it would be possible to so speed them that the feed would be automatic.

However, if the auger machine were added, it would prove better to dispense with the plunger machine, and run the tile on the auger machine direct. As before stated, the plunger machine has many disadvantages which are largely overcome by the use of an auger machine. Another handicap of the geared plunger machine is that it is speeded to give a definite, limited number of strokes per day. Every time a useless stroke is made, or the tile is spoiled, just that number will be cut from the day's output. For instance, all of the clay cannot be expressed at each stroke; in fact, a large amount is retained in the head of the machine to act as a cushion. This excess clay will become too dry or hard, which necessitates the removal of the head plate of the machine two or three times a day, and pushing the great lump of hardened clay out, to be returned to the tempering machine. Much time is lost in this way, or, in other words, many strokes of the piston, each of which should produce a tile, are lost. Other interruptions also intervene in the same way. Further, the plunger machine has a fault characteristic of itself in that it entraps air into the bar of clay more than any other type of machine. The piston, coming forward, closes the feeding opening, and compresses the clay so quickly that but a part of the air is able to escape. This entrapped air may escape in part around the plunger head, but what cannot escape in that way must pass out with the clay bar. It may show as blisters on the tiles, or may produce laminations or open cavities inside the bar. In the case of hard-burned tiles it is not likely that these laminations will give trouble; but should

the tiles be under- or soft-burned, then water may accumulate in these open spaces and freeze, and the tile will then surely go to pieces.

With the intermittent flow of clay from the plunger machine, it is not necessary to use a reel or continuous cutter. A simple hand cutter is all that is necessary, as there is time to cut the tile and remove it during the return of the piston to its starting point. This cut-off is simple and easy to operate.

About the only thing that can be said in favor of the plunger machine is that it allows the cutting and offbearing of the tile to be accomplished with more care than when using the trowel method for the removal of the product of a continuously moving bar. The average output of this plunger machine at this plant is about 4,500 tile per day, as against 10,000 to 12,000 by the use of an auger machine, employing the same number of men in each case. This shows that the additional time for handling must be considerable.

The use of this geared plunger machine, with its limited number of strokes per day and its small output per stroke, is by no means the best that could be done. The direct-acting plunger machines, using steam cylinders as the motive power, are very much more efficient in sewer pipe, brick and hollow tile manufacture, and can handle large tonnages per day. Their gain lies not only in the larger capacity of the cylinders, but in the delicately controlled power by which the flow can be regulated to a nicety. The last clay in the cylinder can be expelled at substantially the same rate as the first, and as fast or as slow as is desired. By cutting several tiles at one stroke, the proportion of waste could be very materially reduced. In fact, the Cincinnati machine represents about the low-water mark of plunger machinery operation.

The faults of bar structure and the intermittent nature of the flow, however, are matters that cannot be overcome by any plunger machine.

Screw or Auger Machines.—The general principles of the auger machine are well known, and require no extended description. Essentially it consists of a barrel, usually horizontal, and either cylindrical or conical in shape, through which runs a center shaft, which carries a series of cast or forged sections which combine to make a more or less complete screw. The clay is fed into the rear of this barrel, and is carried forward by the screw, and forced out of a more or less constricted die in the front in the form of a continuously flowing bar or column of clay.

The different makes of auger machines have naturally played almost all possible variations on the different features of the auger machine. For instance, the shape of the barrel varies from a pure cylinder to a pure cone, or combined part cylinder and part cone, and in some cases they are of oval or elliptical cross-section. The frame varies from cast iron to structural steel. The driving may be done by single gears, double, or even triple gears, with ratios ranging from four to one up to twenty to one. The driving mechanisms include belts, which are the

important method; direct connections to shafts by gearing; electrical drive; and rope drive. The auger shaft may be cast or forged. It may be equipped with a complete screw slipping on in sections, or it may be a series of forged knives or blades, set so as to collectively form a highly interrupted screw. The thrust block or bearing at the rear of the auger shaft is like the step of the dry pan, the point where trouble is first likely to manifest itself. The enormous forcing power of the whole machine is concentrated on this one point, and heating is very sudden if the lubrication is imperfect or the alignment of the end plates gets disarranged. Auger machines also vary enormously in size, from giants able to force out five hundred tons of clay through a two and one-half inch by four inch nozzle in ten hours, down to toy sizes that will scarcely make ten tons of ware.

Auger machines have been developed most extensively with an eye to the brick industry. Their use in producing hollow goods of all sorts and roofing tiles is distinctly of secondary importance. Hence we find the auger machines used in the roofing tile industry are usually the smallest sizes of brick machines equipped with the dies. Only a few auger machines have been developed especially for roofing tile purposes.

The critical features of the auger machine are: First, the auger for forcing the clay out; second, the die, through which it is forced. All other parts of the machine may be built in various ways without specially affecting either the power required to drive the machine, the quantity or quality of the output. They may, of course, affect the size, weight, frequency of breakdown, ease of access for repair, etc., but they are not essential points.

The auger, or screw, as before stated, may be made in sections to slip on the auger shaft, one after the other. In some cases the fittings are merely blades set with a slight spiral twist, and forming a slightly interrupted screw, and sometimes they are a set of steel-forged knives set at a variable lead at different points on the shaft. However, in all cases the effect secured is that of a screw.

The front end of the auger shaft is fitted with a casting having a spiral thread of large pitch, making one or more complete turns around the core, or axis. This casting is called the auger. It is designed to gather up and compress the clay delivered to it by the segmental screw made by the knives or blades farther back on the shaft. While the clay is being compressed it is being pushed forward to the die, through which it passes under much pressure, taking its final shape as it comes out.

The auger may be made up of a single spiral, in which case it is necessary to have a spacer or collecting chamber placed between the end of the auger and the back end of the die. This is necessitated by the clay coming from the auger in a single stream, which follows the turns of the auger about the die entrance. Should the auger and die be placed too close together, it would be found that the column of

clay issuing would not flow regularly and true, but would wabble or lunge from side to side as the opening in the auger passed from side to side. By putting in the spacer and making a collecting chamber, it will be found that the unequal or irregular pressure of the auger is overcome in part or completely. The character of the clay as to slipperiness, and the necessity for the product to be sound or devoid of structure marks, will determine whether this type of auger is suitable or not in any given case.

For instance, in Chicago common brick yards, a single-threaded auger of large pitch is used, and enormous quantities of brick are made per day from a fat, sticky, slippery clay. The structure is very bad indeed, the bar being composed of spirally disposed layers, separated by laminations or unbonded zones. For the purposes in view this bar structure is a matter of indifference, and quality and smoothness of exterior are the only criteria.

For a paving brick plant such a course would be out of the question, for a bar as nearly devoid of laminations or spiral structure as possible is here necessary.

In these cases augers are made with two threads, or "double bitted." This style of auger overcomes to a large extent the trouble of the single-thread type in that the clay is delivered to the die in two streams, which blend into one another and make a more regular and uniform feed. In the manufacture of brick it is rarely necessary to go beyond the double-threaded auger to get a bar of even flow and good structure, at least with the intervention of a collecting chamber.

In some brick clays a poor structure results even with a double-threaded auger and intermediate collecting chamber between the front of the auger and the back end of the die. The length of this chamber is of great importance. It must be determined by experiment in each case. The correct distance is manifested, when found, by a greatly improved structure of bar.

In some cases, chiefly for products like shingle tiles, drain tiles, or bars of small cross-section and hence of exaggerated tendency to laminations, augers of three threads are employed. They look almost like the propellor of a steamship. The three streams of clay, blending into one, do away with uneven or convulsive flow to a very complete degree. The clay is delivered to the die in a steady, continuous feed, with equal pressure over the entire area of the die at all times. It is thought that a short collecting chamber, even with a three-wing auger, would be advisable, though at the United States Roofing Tile Company they use none, and the distance from auger to die is only two inches, and a bar of good structure is obtained.

Should a single-wing auger be used for roofing tile, it should be provided with a lip, or projecting flange, along the edge to prevent the clay from slipping or working back while under pressure. The collecting

chamber should be long—say twelve or fifteen inches. This will permit of the equalization of the flow and break up the laminations in part, but at the same time it will require a great deal more power to operate the machine.

The auger, assisted by the more or less interrupted screw behind it on the auger shaft, constitutes the propelling force of the machine. The die is the shaping mechanism, which forms the clay into a bar of the desired cross-section. A flow-die is simply a tube through which the stream of clay flows. It limits the shape or cross-section of the clay bar on two axes; the third axis, being the line of flow, is indefinite and unlimited.

The nature of this tube is, however, a matter of the gravest concern for on it depends the smoothness or surface perfection of the clay product. If the tube is perfectly straight—that is, of the same dimensions from end to end—the bar would be of bad structure and the power required to operate it would be enormous. If the tube be conical, with a larger area in the rear next the auger, and a reduced cross-section, the clay will feed into it better and less power will be used. But if the nozzle is the smallest point in the tube, the bar would tend to ruffle, or flow with a rough, cracked or scarred exterior. The usual plan is to combine a conical or sloping cross-section for the rear half or two-thirds, with an almost if not quite uniform cross-section in the front portion.

The bar thus formed in the rear of the die compresses and elongates as it slips forward and in the front portion is "slicked up," or smoothed for its final surface.

The variations in dies are innumerable. Only a few will be discussed here, and those chiefly in connection with the plants or machines in which they were observed.

The following auger machines were observed in use in the roofing tile plants of the country:

The Murray Machine.—This machine is the most largely used in the manufacture of shingle tiles. It was designed by Mr. A. H. Murray, of Cloverport, Ky. Its pugging chamber is short, and situated a little above and attached to the case containing the auger. The auger and die are the important part.

This machine is simply a small combined pug mill and auger machine. The pugging chamber is not over four feet long, the auger case and die possibly two feet more. It is only about four feet high. When these figures are compared with those of the ordinary sizes of combined pug mill and auger machines, it will be seen that it is very small indeed. The clay has to be prepared by other pugging or tempering machinery before being fed to the Murray machine. In the Murray machine the die is made to act as a collecting chamber and a die at the same time.

Four plants were found to be using the Murray machine. The Huntington Roofing Tile Company, two machines; the Murray Roofing

Tile Company, one machine; the Ludowici-Celadon Company, at Chicago Heights, Ills., one machine, and the same company, Ludowici, Ga., one machine. While this machine is small, its output is equal to that of the larger machines, averaging daily about 12,000 shingle tiles. The main difference, however, lies in the fact that the clay must be run somewhat softer than it is in the larger machines. This point is not a serious objection, except that a higher shrinkage of the tile is likely to be encountered, and this high shrinkage is very apt to produce a larger per cent. of twisted tile.

The combined pug mill auger machine made by the J. D. Fate Company, of Plymouth, Ohio, is apparently very popular among the roofing tile manufacturers. Not less than six of these machines were found in use. There were three different sizes, named the "Hummer," the "Premier," and the "Imperial," of which there were two each.

The main reason for the popularity of the Fate auger machine is that the double shaft pugging-part gives the clay a very good mixing or working before it enters the auger. Also, the head of the machine is so arranged that it is very easily opened for cleaning and changing dies. The strength of the machine is such that little trouble has been encountered from break-downs. It is true that other makes of machines on the market meet the same conditions, but so far they have not been able to force their way into use to nearly as large an extent as the Fate machine.

The American Clay Machinery Company, of Bucyrus, has four auger machines in the roofing tile industry, viz., at the New Lexington plant of the Ludowici-Celadon Roofing Tile Company a No. 1 "Giant" and a No. 2 "Giant" at the Alfred plant of the same company, a "Centennial," originally made by the Frey-Sheckler Company (now the American Clay Machinery Company); at the Alfred Clay Company, Alfred, N. Y., a No. 2 "Giant."

The Bonnot Company, of Canton, Ohio, has one auger machine in use in the roofing tile field, viz., at the New Lexington plant of the Ludowici-Celadon Company, where a No. 2 Bonnot is used for shingle tiles, blanks and other work.

Mueller Brothers, 2935 Clark avenue, St. Louis, Mo., make a small auger machine for the roofing tile industry, the distinguishing peculiarity of which is the use of two parallel auger shafts, whose streams unite in one die to produce a single bar of clay. They sell the larger part of their output through the Illinois Supply and Construction Company, of St. Louis. These machines are in use by the Mound City Roofing Tile Company, and the Detroit Roofing Tile Company, and single shaft machines of the Mueller plant are in use in the laboratories of the Ohio State University, at Columbus, the Bureau of Standards, at Pittsburgh, and Edward Orton, Jr., at Columbus. (See figure 19.)

As to the success of these small machines, there is not much to be said, because the companies using them are not working them at all closely to their limit. However, at one of the plants, the objection is raised against them, that the augers will wear unevenly and the feed of the clay into the die then becomes unequal on both sides of the tiles, causing one side of the tiles to run faster than the other. Such tiles, of course, cannot be used on account of the warp or bow given them. These machines are much too light for heavy or continuous work. The clay has to be run much softer than it otherwise would.

It seemingly is somewhat difficult for many people to understand that it takes more power to run roofing tiles through a die than it does ware of larger cross-section, the reason being that the proportion of frictional area in the case of tile is far greater in proportion to the quantity of clay than it is in the case of side-cut brick for instance. Many have thought that because very little clay is used in tile, that it only requires a small, light machine to handle it. Such is far from the case. The auger machine for making roofing tile should be built upon generous lines, with much strength, so that the tiles can be run from stiff clay and put under much pressure in passing through the die. The actual barrel or drum of the auger does not necessarily need to be large, but the auger and its thrust-block should be given much attention. The gearing should be strong and accurately made.

Cutters.—After the clay has been extruded from the die in the form of a continuously moving bar, the question of cutting it up into lengths while in motion is to be overcome. Automatic cutters, moving at the same speed that the bar moves, are produced by practically all manufacturers of auger machinery. These necessarily are adapted, each to some special tile, and for this reason will be discussed in connection with the machine and the plant where they were seen in operation.

A large part of the work of auger machines in the roofing tile plants, is in preparing blanks for subsequent pressing on power presses. This purpose is a much easier one to fill than to make a finished tile by auger machine alone, as poor surface or bad structure may be overlooked, if they do not persist through the subsequent pressing, which they generally do not.

Presses.—The presses used in making roofing tiles may be classified as in the following tables:

Hand Presses	Screw. Toggle.	
Power Presses	Pentagon	Crank. Eccentric. Toggle.
	Trimmings	Crank. Toggle.
	Special.	

The various roofing tile presses used for the making of roofing tiles and tile accessories are in considerable number, and it would almost seem that each plant was trying to solve the problem of making the best tile press for itself. There are in use, at the present time, revolving presses made by seven different companies as follows:

Rogers Machine Tool Company............Alfred, New York.
American Clay Machinery Company.......Bucyrus, Ohio.
Fisher & Koontz, Machinists..............Parkersburg, West Virginia.
East Iron Machine Company ....Lima, Ohio.
Crawford & McCrimmon Company ....Brazil, Indiana.
Illinois Supply & Construction Co.........St. Louis, Missouri.
Ludowici-Celadon Company..............Chicago, Illinois.

This latter company does not manufacture presses, but for two of their plants they have had presses built for them, from the patterns of a German press largely used by the Ludowici's in France and Germany.

In taking up the study of the revolving power presses as a whole, the first thing observed is that they all have one common feature, i e., the revolving pentagon upon which the dies are placed. The chief differences in the presses are in the methods of applying the pressure, and the shape of the frames of the press.

There are two modes of application of the pressure, first, by crank shaft, cams or eccentrics, and second, by toggle-joint movements.

The presses using crank shafts can again be divided into two classes, first, those in which the entire gearing is attached to the main frame work of the machine, and second, those having a solid base, but with the gearing separate from the main frame work.

Crawford-McCrimmon Press.—This company was undoubtedly the first to manufacture a revolving pentagon press in this country. Their press is of the eccentric type, having the gearing attached to the frame of the press.

As shown by the cut, the press consists of two side frames, connected at the top by a curved yoke. Carried upon the upper part of the frame is a shaft, on which the belt or driving pulley and the fly or balance wheel are placed side by side. This shaft carries a small gear or pinion wheel on the other end which intermeshes with the large gear wheel shown on the right of the press. This latter gear drives the main shaft which extends across the press, carrying the two eccentrics which are connected by two threaded rods each to the cross head or plunger of the machine. The cross head works up and down between guides attached to the side frames of the press. To the under side of the plunger is attached the upper die.

The large gear wheel has fastened to it a stud-bolt, which projects outward. This stud or "trip" as it is called, is so placed that it engages one member of the spider wheel, shown on the right side of the press, below the main gear wheel, at each revolution. Immediately back of the spider, near the frame work, can be seen a wheel or collar in which

pockets are cut. These pockets are to receive the plunger or pin, shown above the lock or pocket wheel. The main shaft to which the spider wheel is attached carries the part of the press called the pentagon, upon

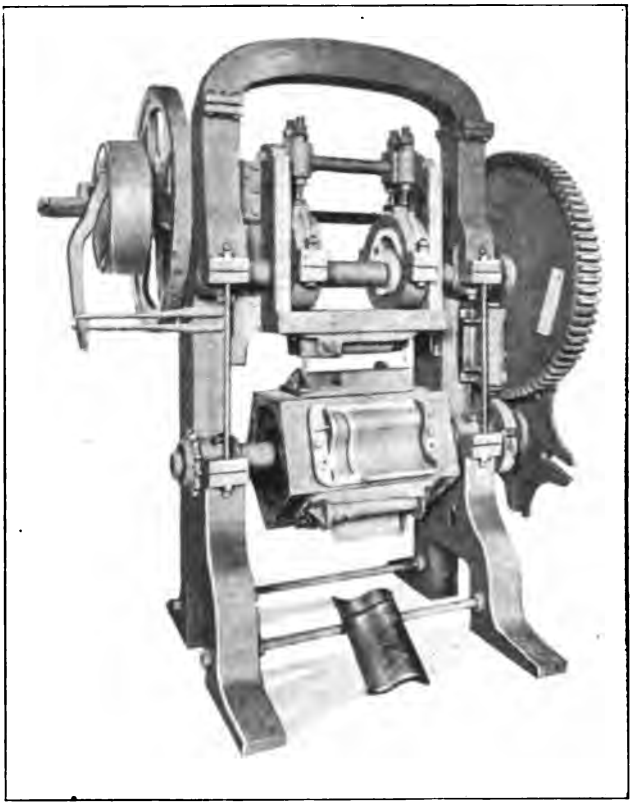


Fig. 66—The Crawford & McCrimmon Roofing Tile Press.

which the lower dies are placed. The operation of the pentagon is actuated by the trip pin engaging the spider wheel as the main gear revolves. At the instant the trip pin engages, the lock pin or plunger, which holds the pentagon firmly while the pressure is being made, is released and the pentagon revolves one-fifth of a revolution. The top die descends, making the pressure, then raises, and the pentagon is tripped, and turned one-fifth of a revolution again, and so on.

While quite a number of these presses have been made and sold by the Crawford & McCrimmon Company from time to time, there was only one in use at the time of the visits made to the various plants of this country.

One objection to this press, and the same applies to all presses of this type, is that the main driving mechanism is attached directly to the press, and too far from the base. In other words, the machine is

top heavy. The constant strain and racking of such a press is far greater than in the type where the power is applied lower down and separate from the frame work.

The Grath Press.—This press is manufactured by the Illinois Supply & Construction Co., at St. Louis, Mo. The main difference in this press over that just described is in the method of applying the pressure to the plunger head.

It will be seen that a crank shaft is used in the place of eccentrics. While the crank shaft may be a better mechanical movement than the eccentric, the manner in which it is used in this case is a disadvantage in as much as the pressure to the plunger is applied at the center. The cross head or plunger must depend entirely upon the guides to hold it true, in case there is an excess of clay at one end of the die over that at the other. While it is true that all presses must depend on the guides to properly center the upper die with the lower one, it is certainly better from a mechanical standpoint to apply the pressure equally at both sides of the plunger, rather than at one point.

This press also differs from the Crawford-McCrimmon press in the matter of locking or holding the pentagon in place for the pressure.

This feature as shown in the cut consists of a raised rib or lug cast on the main gear wheel. This circular rib engages with the spider wheel direct, as shown. At the point where the trip pin is located, a section of the rib is cut away, thus allowing an open space to permit the spider to turn one-fifth of a revolution. There is an objection to this feature, arising from the wearing away of the segmental sections on the spider, allowing the pentagon to have more or less play backward and forward. With dies using trimmers, such conditions cannot be tolerated at all. The pentagon must register exactly with each motion.

It is plainly seen that the wearing surface of the individual segments of the spider is far less than that of the interlocking rim, and will therefore wear away much faster. This could be overcome by making the spider much larger, and the holding rim smaller, or by providing renewable wearing surfaces at the critical points. There was found but one plant using the Grath press, viz., The Detroit Roofing Tile Company.

The Ludowici press made in America from German patterns, is of the same general type as the two types just described, although not built so heavy. This is easy to understand when it is known that the Germans are as a rule using plaster dies and must necessarily work their clays much softer than they would if metal dies were used. They have, therefore, not built presses as heavy as the American firms, who have had to build with a strength to accommodate metal dies and stiff clay.

Presses with Separate Driving Mechanism.—This type of press has the main drive gearing on the same bed plate as the press proper, but not on the same frames, thus relieving the press frame of the overhead load.

In this general type of press are embodied the best mechanical features, and it will without doubt prove to be the press of the future. There were eleven of these presses in use in the various plants at the

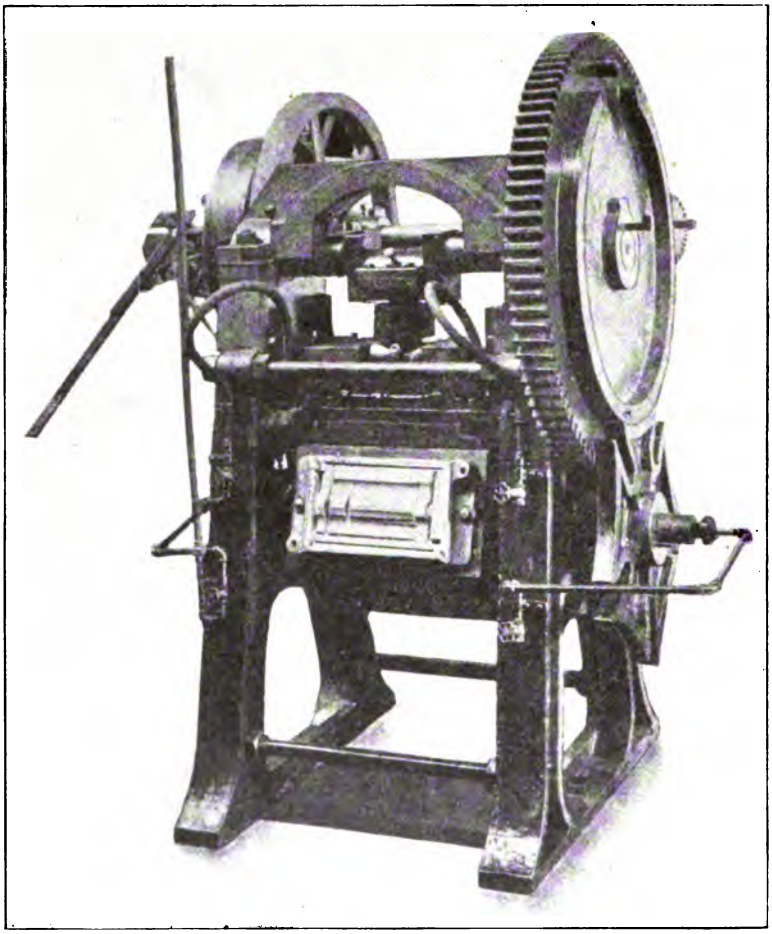


Fig. 67—The Grath Roofing Tile Press.

time of taking the field notes for this report. The eleven presses in use were made by three different firms. Six of them by the Rogers Machine Tool Company, three by the American Clay Machinery Company, and two by Fisher & Koontz.

The Rogers Press.—The Rogers Machine Tool Company has the largest number of presses in use at the present time. They well deserve this credit, for they were the first to produce a machine of distinctly different type from the foreign presses. The following illustration shows one of the early presses developed by this firm, a few of which are still in existence.

This press has been modified and improved until the most recent form put out by this firm has diverged quite widely from the starting point.

It will be observed that this press is constructed upon generous lines. The entire press stands upon a solid bed plate, to which are attached the two heavy upright frames .carrying the pentagon and plunger. To the left of the main frame, and on the same bed plate, are the two upright pedestal bearings which carry the primary and secondary driving mechanism. A heavy fly wheel is attached to the primary shaft, which in turn is controlled by means of a friction clutch pulley. The secondary shaft, shown on the top of the pedestals, drives the shaft which carries the eccentric to operate the plunger by means of a small pinion.

It will be observed that the cross head or plunger is very large, having the two side frames with side and back face plates for guides. At the upper right hand corner of the cross head can be seen a gib or take-up. This is used to provide for the slight wear that may occur on the face of the guides.

The spider wheel is made very large, thus affording a large bearing or leverage surface for holding the pentagon steady.

The trip wheel is shown just above the spider, and behind the large upper gear wheel. This trip wheel is provided with a case-hardened steel roller and pin, which enters the slots of the spider wheel and turns it one-fifth of a revolution at each stroke of the pressure head. The capacity of such a press is about 5,000 to 6,000 tiles per day of ten hours, and requires about ten horse power to operate it.

The American Press.—The press of the American Clay Machinery Company is of this same type, very little difference having been made in its design. The main advantage claimed by its manufacturers, is in the manner of making the main housings or frames of the press. In the Rogers press they are cast in one solid piece, while the press in question has the housings cast in two parts each, depending on the strength of two steel rods to each housing to take care of the pressure between the head and pentagon.

Fisher & Koontz Press.—This press is practically the duplicate of the one just shown. Hence a description is unnecessary.

It will be observed from the illustrations of the presses shown, that the true American roofing tile presses are equipped with double back gearing, while the presses of the German type have single gearing only. The double gearing assists the press in the matter of steady, uniform speed. The effect of the pressure is scarcely noticeable at the driving belt.

The Klay Press.—The Klay press is manufactured by the East Iron Machine Co., Lima, Ohio. It was designed and patented in 1901, by

Mr. A. B. Klay, of Lima. In 1908 only two of these presses had been installed, both being in use by the National Roofing Tile Company at Lima.

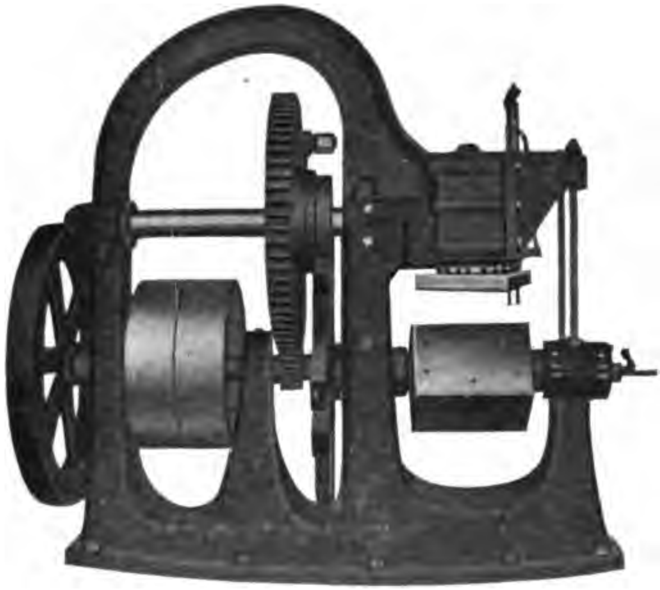


Fig. 68—Early Form of the Rogers Roofing Tile Press.

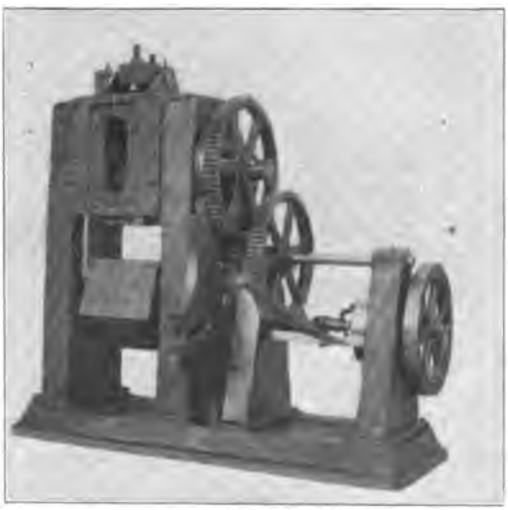


Fig. 69—The Rogers Machine Tool Company's Roofing Tile Press.

The Klay press differs very widely from all other makes in the matter of applying the pressure to the plunger head by toggle joints instead of the crank or eccentric.

It will be seen from the cut that the press stands upon a cast bed plate, upon which are erected the two tall housings on the right and the pedestal bearing on the left.

It will be observed that the machine is belt-driven. The main driving shaft carried a pinion which engages the gear wheel shown to the left side. This gear in turn is attached to a shaft carrying two pinions which work against two large gear wheels shown below. These large gear wheels are made with cams which in turn operate the plunger shown just above the cam gear wheels. The plunger, it will be seen, is attached to, and operates the toggle joint just above it. This toggle in turn is connected to the main toggles which operate the plunger head. Thus with all of the compound movements, an enormous pressure is exerted at the pentagon. The pentagon is operated by a small sprocket or trip wheel which meshes with a segmented one on the cam shaft.

It will be noticed that there is a double set of toggles at the plunger. The inner or large ones operate the plunger, and give the pressure, while the smaller or outside ones operate the frame around the upper die, called a trimmer. These latter toggles are made a little longer than the main ones, so that as the plunger descends, the trimmer moves down a little faster and farther than the plunger-head. By so doing, it reaches and encloses the lower die before the pressure is applied. Thus the clay is held securely in by the trimmer so that when the pressure is released the tile is left with perfectly smooth edges, requiring no trimming. The dies on this press are made of "white metal," and heat must be supplied to make the clay release. This is supplied at the upper die only, steam being used. The hose pipe shown in the cut, which enters between the toggles, conveys the steam into the hollow backing of the upper die. A small pipe can be seen extending across the front of the upper die on the pentagon. At the bottom is another, and one in the back is placed so that it is in proper line for the upper die. These small pipes are for spraying oil upon the dies by means of compressed air. This pipe system is so connected with a trip that it automatically sprays the oil at the proper time when the plunger is up, thus doing away with the bothersome and expensive hand method of applying the oil.

While this press has had but little opportunity to demonstrate its working qualities, outside of this one plant, it was claimed by those using it, that it had given very good satisfaction there. The press, however, is very much more expensive than the other types of presses built in this country. The ordinary presses cost from $800.00 to $1,500.00, while the Klay press runs very much higher.

Fig. 70—The American Clay Machinery Company's Roofing Tile Press.

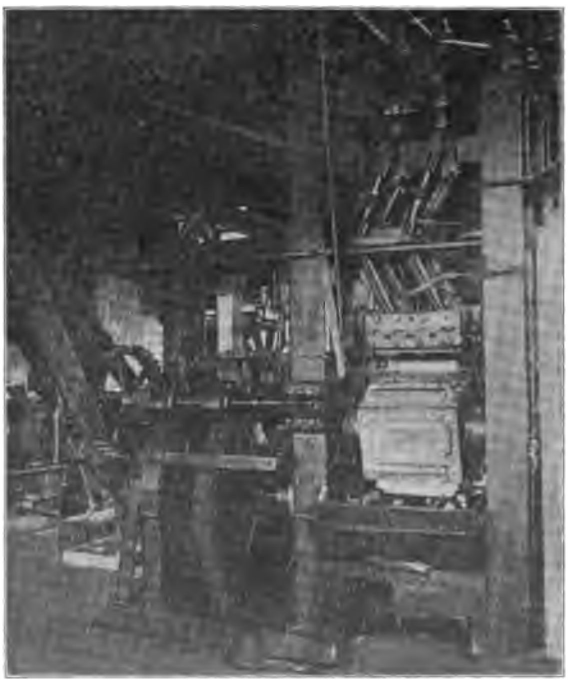


Fig. 71—The Klay Roofing Tile Press. (National Works, Lima, O.)

SPECIAL OR TRIMMINGS PRESSES.

These presses differ from the pentagon presses in that they are usually made to carry one die only. Their use is for the special pieces that must be used with the regular tiles to make a roof complete. They produce such shapes as eave tiles, top or ridge tiles, hip rolls, crestings, etc.

The press used for this purpose differs quite widely in the method of applying the power. Five machine firms were represented by presses manufactured in this country, while a press manufactured in Germany has found use with one American company.

The American firms were as follows:

The C. W. Raymond Company	Dayton, Ohio.
Illinois Supply & Construction Co	St. Louis, Missouri.
Rogers Machine Tool Company...........	Alfred, New York.
American Clay Machinery Company	Bucyrus, Ohio.
East Iron Machine Company	Lima, Ohio.

With the exception of the Raymond press, these presses are all power driven. In the selection of a trimmings press, much care should be used, output and ease of operation being the primary objects of attention.

In the foreign countries, screw trimmings presses have been very widely used in the roofing tile industry, but in our own country the screw press has found but little or no use in this industry. There are hundreds of screw presses in use in the dry press tile factories, making wall and floor tiles, but for plastic clay they are not popular. The American manufacturer wants a press that can be operated more quickly than a screw press.

The Raymond Hand Press.—This hand press has found the greatest use in this country of any hand-power press. It is known as the "Perfection Hand Press." It is made in three sizes, the No. 3 size being the one most in use. (See Figure No. 120.)

It will be seen that the press is of the toggle joint type, the pressure being exerted by bringing the toggles to a vertical position, which is accomplished by pulling the hand lever down. This press when properly arranged, has a sliding track arrangement, whereby the tile dies are moved back and forth to receive the pressure, and then to dump the tile onto a pallet.

For varying thicknesses or sizes of dies, provision is made to move the upper head up or down by means of screw and hand wheel. This adjustment can be made very quickly. The pressure exerted by the mechanism of this press is sufficient to make dry press brick, hence for plastic clay ware it is ample at all times.

Its daily output depends largely upon the operator and the size of tiles made, but under average conditions it is possible to make 500 pieces, but more often the output will not exceed 300 pieces per day.

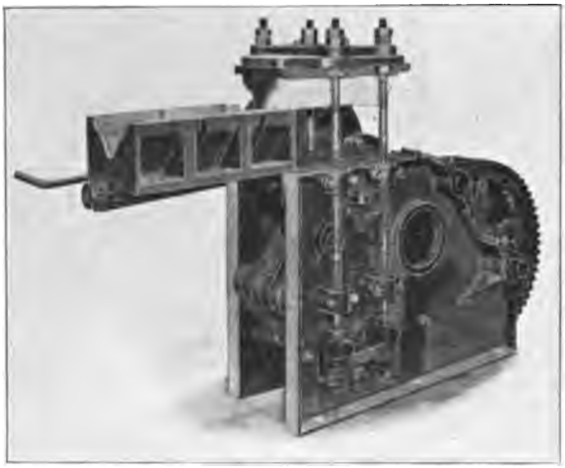


Fig. 72—The Grath Trimmings Press. (Illinois Supply & Construction Company.)

While this press has found quite a wide use among the roofing tile manufacturers, it has one feature that is not desirable. By reference to the cut it will be seen that the pressure is applied from below, raising the lower die up against the top die, which in turn remains stationary. This, however, should not be the case. The top die should be the one to move and the lower one remain stationary, for the following reasons: In the nature of the case, tile dies are heavy, and in addition to the dies, the weight of the track or dumping mechanism rests on the die platform, so that the man at the lever has a dead load, amounting at times to 200 pounds, to raise at the pressing of each tile. In part, this load is relieved by the side springs shown in the cut, but the tile manufacturer has so many dies to be used on a press of this kind that it is not usually possible to keep the springs properly adjusted to equalize the weight of each one.

The above objection to the press is possibly no more serious than having the sliding track moving up and down with each pressing. For various reasons it is desirable to have the track remain at one level, especially if the press is fed from both sides. Another objection to this press which will apply to all hand presses is that it requires two men to operate it properly, one at the die and the other on the lever. The same work can as well be done by one man if the press is fitted for power.

The Grath Trimmings Press.—Of the power presses for special work, this press has found a considerable use and well deserves its popularity. It is small and compact, requiring but very little floor space, and is easily operated by one man.

By referring to the illustration it will be seen that the press consists of two cast side frames, or housings, which practically enclose all of the working parts of the press. On the opposite side, back of the die in the cut, is the driving pulley. This is on a shaft, which in turn carries two pinion wheels, which drive the two large master gears shown at the back of the press. These carry a cam, which in turn operates a connecting rod that is attached at its outer end to the toggle joints shown below the die. When these toggles are pulled to a veritcal position they transmit pressure to the upper die by means of the four large rods working in guides at either side of the press. The lower die is arranged to slide in and out upon a rod to which it is hinged. It is a very easy matter to dump the largest dies by turning them over with the handle shown at the end of the die in the cut. For the proper adjustment of the upper die to suit the varying thicknesses, it is necessary to raise or lower the nuts on the four upright rods. If this feature were improved, the value of the press would be very much enhanced. In addition, the press should be built with a higher lift, it being now impossible to make ware of much depth. The weight is all below, and the lower die does not move up and down with the pressure, as in the Raymond press, both of which features are desirable.

American Trimmings Press.—It will be seen (Figure 73) that this press is built upon very different lines from those of the Grath press.

It consists of a main central frame, or housing, a part of which forms the journal bearings for the driving and crank shaft. Two upright guide rods carry the cross head to which the upper die is attached. It will be noticed that relieving springs are employed to allow a slight give to the cross head in case of excessive pressure.

The four connecting rods connect the crank pins, riveted into the crank gears at either side of the press. The crank gears are provided with counterweights to balance the upper cross head. The power is applied at the friction clutch pulley, which in turn drives a shaft carrying two pinions that engage the large crank gears. Suitable sliding track arrangements are made for the lower die. Considering this press as a whole, it should meet the demands of the roofing tile manufacturer and prove very satisfactory. Only one of these presses was found in use, but this design had not been on the market long at the time of taking the field notes for this report.

The Rogers Trimmings Press.—This press is built along quite different lines from those of the American or Grath. It is, in a general way, patterned after the Rogers pentagon press, in that the main housings and outbearings stand upon a heavy one-piece bed plate, thus making a much heavier, and at the same time a more rigid, press than those having outbearings resting on separate pillow blocks or foundations.

From the drawing on page 264 it can be seen that the press consists essentially of the solid bed plate, with the two outbearings on the right, while at the left are the two main housings. These are connected at the top by a heavy cast iron yoke.

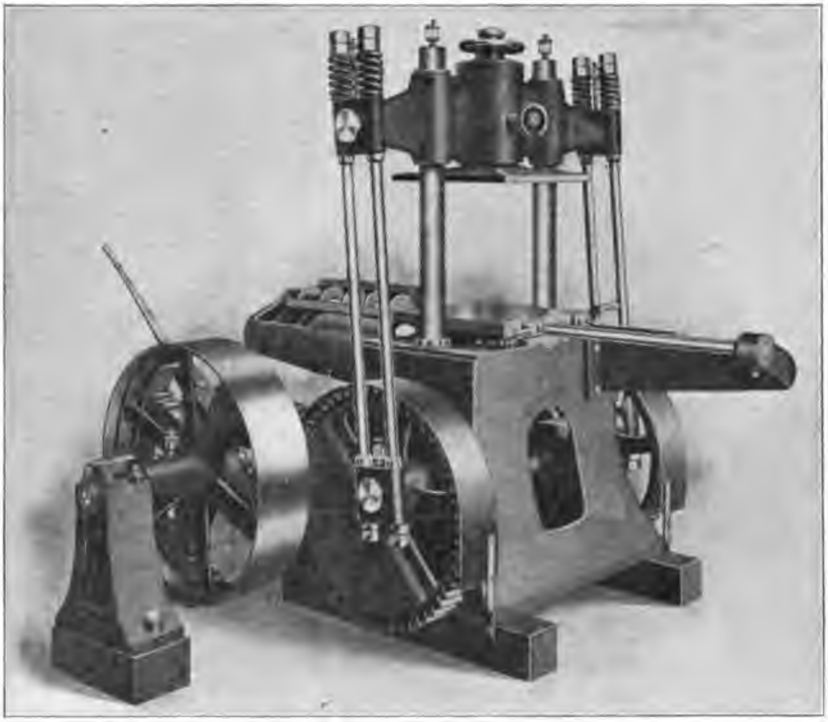


Fig. 73—Trimmings Press, made by the American Clay Machinery Company.

The driving mechanism of the press is of the double back-geared type. The main driving pulley is carried by the shaft resting in the bearings at the top of the outbearing blocks. This primary shaft, in addition, carries the pinion wheel at the extreme right, which meshes with the large gear wheel on the secondary shaft. The secondary shaft extends across the face of the main housings, being attached to the same by bearings. The power is delivered from the secondary shaft through the two small pinions to the large crank gear wheels, one on either side of the press and connected by a shaft. From the crank wheels the power is delivered to the main cross-head by heavy rods, two at either side of the press.

The cross-head is made very large and heavy, and travels or reciprocates in guides formed by the side housings. Attached to the cross-head is a large face plate, to which the dies can be bolted. A convenient arrangement is provided to raise and lower this plate so that it can be adjusted to suit different dies and to regulate the thickness of the ware.

The main table upon which the lower die is carried rests on a heavy casting or bed plate which extends from housing to housing. The die table is conveniently arranged to move out from under the press to facilitate the filling and dumping. The press is built so that either a single or a double dumping table can be used.

Experience in the past has been that it is more satisfactory to operate any trimmings press from one side only. The better practice where greater output is desired is to use two presses.

The Rogers press has found a wider use than any of the other trimmings presses described in this report. It has, however, been on the market longer than most of the others, but in turn it has a number of excellent features. It is self-contained, double back-geared, the main housings are heavy and large, thus forming exceptionally good bearing surfaces for the guides. The adjustments of the upper die can be quickly made, and furthermore the lift of the upper die is ample to care for ware of high projections.

Mueller Hand Press.—This press is quite small and is arranged for hand driving. It is operated by taking a previously prepared blank of clay and placing the same on the lower die, which is between the hand crank and the large gear wheel. The upper die is then pulled down into position. The roller pins at each end of the die engage with the cam or eccentric wheels attached to the main gear wheel shaft. The crank, which is back-geared against the main gear wheel, is then turned until the cams have made one complete revolution. The roller pins of the upper die thus being released, the die is raised. A pallet is now placed over the tile resting in the lower die. This die is so hinged that it can easily be turned over, thus emptying the freshly made tile onto the pallet. The die is then turned back into its proper position ready for a second tile.

There is little that can be said in favor of this press, although by arranging to drive it by power so that its speed would be increased it is quite possible that it could be used on special or complicated tiles and trimmings. As it stands though, it is quite foreign to the American way of doing work. While a number of these presses have been placed in drain tile and brick plants for the manufacture of a few roofing tiles, none of them have found their way into any of the true roofing tile plants.

Laeis Trimmings Press.—It will be observed that this press is different from the American presses. Its essential parts are as follows: The driving pulley at the right is carried on a shaft supported by an outbearing and a boxing attached to the main housing or frame of the press. This primary shaft is back geared against the large gear wheel shown on the upper right hand side of the press. The shaft to which the large gear is attached extends through to the other side of the press, carrying at the center an eccentric hub which

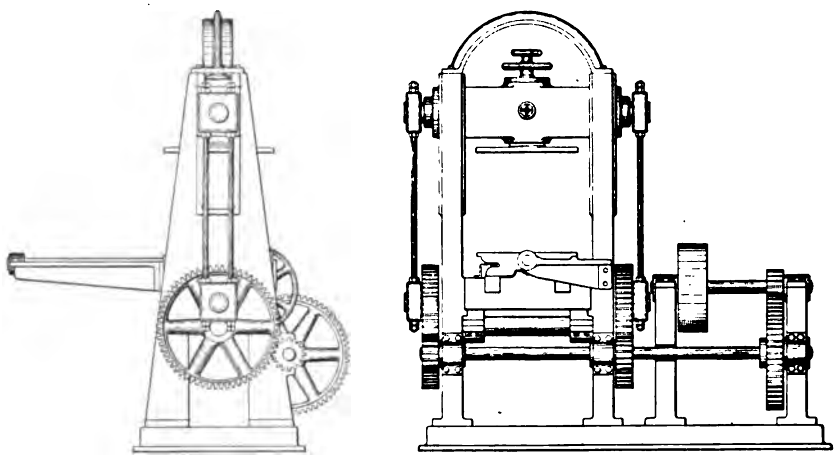


Fig. 74—The Rogers Trimmings Press.

Fig. 75—The Mueller Hand Press.

works against a roller attached to the cross head or plunger. Thus as the eccentric hub on the shaft revolves, the plunger is alternately raised and lowered carrying the upper die with it. The lower die which rests on the bed plate is provided with a sliding track to enable the operator to change and empty it easily. Probably the strongest feature about this press is the placing of the greater part of the gearing above the dies, thus keeping them free from the scrap clay.

Jaeger Trimmings Press.—This press is of the same type as the imported German trimmings press used at the Chicago Heights plant of the Ludowici-Celadon Company.

From figure 77, page 268, it can be seen that the press is built low, heavy and self-contained. The power is transmitted from the driving pulley to the plunger through a long lever or walking beam. While the latter is continuously in motion, the pressure only takes place when the small lever above the upper die is pushed into position by the operator. After each stroke, however, the lever is automatically disengaged as a safety precaution.

It will be observed that this press is so constructed that the dies operate at right angles to the body of the press, and furthermore, the dies are accessible at any point on the sliding track. This feature is of value in case the piece of ware should fail to fill out perfectly and it is necessary to add more clay and press a second time. In the ordinary press the lower die will have to be pulled out from under the plunger in order to add the extra clay.

In this case as in the press shown in figure seventy-six, the gearing is removed as far as possible from a point where it would be in danger of becoming fouled with the scrap clay.

The Klay Trimmings Press.—By reference to the cut (Figure 78) it will be seen that this press is entirely different from any others thus far described.

It consists of four upright frame posts, connected at the top by a heavy casting, which carries the upper die and the mechanism for adjusting the position of the same to suit dies of various sizes. The lower die rests upon a movable table, or plunger, working between guides. Just below and connected to the table, are the toggle joints which transmit the pressure to the die.

The toggles are operated by a long connecting rod which is operated by the cam gears shown on the left of the cut. These cam gears and all the balance of the driving mechanism are attached to an extension of the main frame work.

While the press is undoubtedly very powerful, it has some bad features. Among them are, first, the lower die is moved instead of the upper; secondly, the press is very bunglesome, requiring an undue amount of floor space to accommodate the driving mechanism. More space is taken up by this part alone than is used by the press proper.

One press of this make was found in use during the season of 1908.

Tile Trimmer.—Mention was made of a trimmer in connection with the descripion of the Klay roofing tile press, used to make the sides or edges of the tile smooth and perfect without subsequent work.

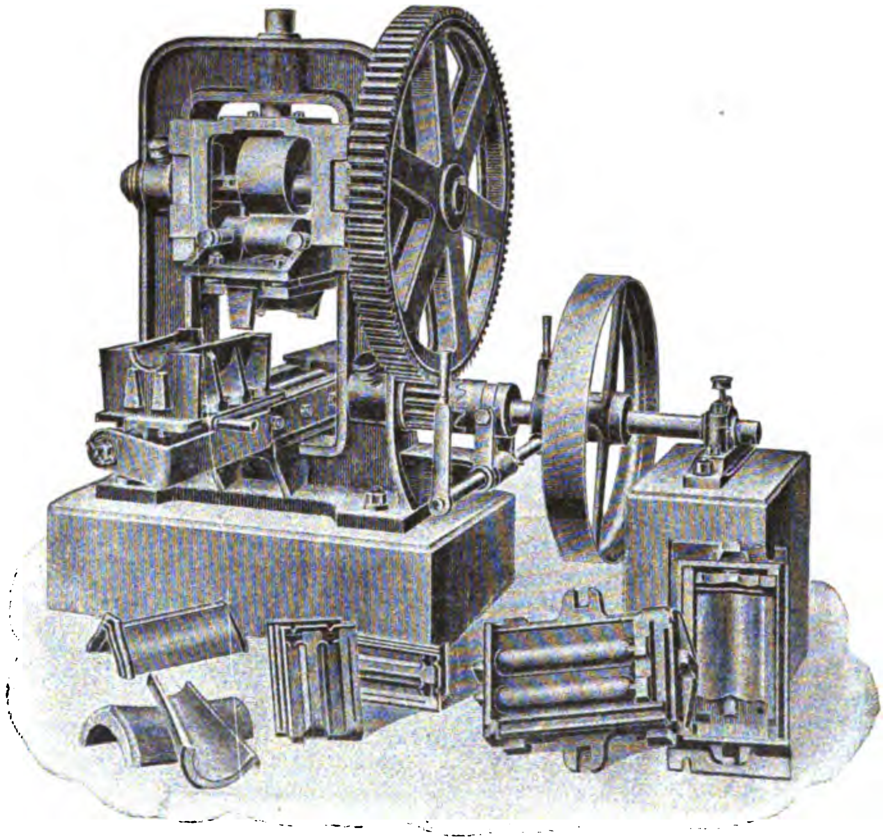


Fig. 76—The Laeis Trimmings Press, made by E. Laeis & Company, Trier, Germany.

With the ordinary dies used on tile presses, it is customary to have the edges of the upper and lower dies meet at a point about midway in the thickness of the tile; that is, the tile is half in the upper, and half in the lower die. It is impossible to keep dies in such perfect condition that they will shut absolutely tight along their sides for any length of time. The issue of the clay soon wears the sharp edges away. Thus, after a tile has been pressed in such a die, it will be found upon being removed to have a ragged seam or "feather edge" on the line where the two dies divided. This feather edge of clay must be trimmed off, and as a rule two boys or men are required at each press to do this work. With plaster dies, the trouble is much worse than with metal dies. To do away with the expense of "skinning" the tiles, as it is called, large

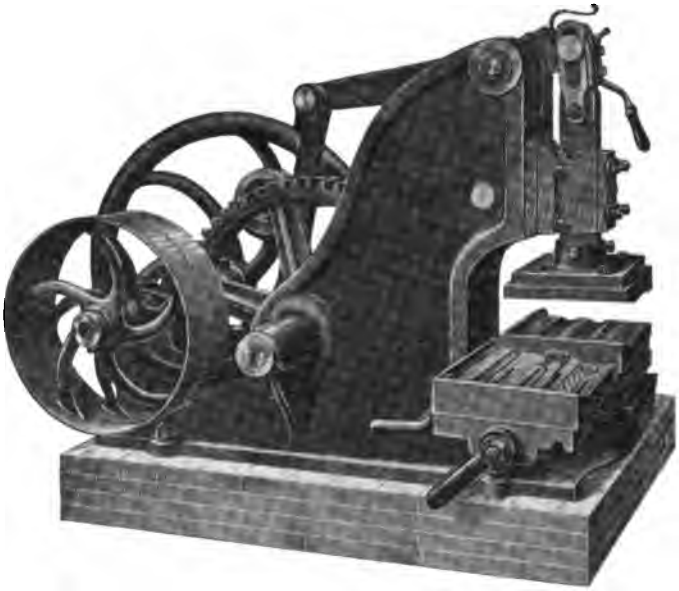


Fig. 77—The Jaeger Trimmings Press.

Fig. 78—The Klay Trimmings Press. (National Works, Lima, O.)

sums of money have been expended to perfect a trimmer that would do the work automatically on the press. The great trouble has been to prevent the clay from squeezing out between the trimmer and die; in this case the feather edge is only changed in position. A trimmer, to do good work, has to be made to fit the die snugly, and if so, at times it will bind, failing to pass over or release from the die, and it or the press is then broken.

So far the only successful trimmers that have been made to work are those used on metal dies.

The trimmer giving the best satisfaction was in use at the plant of the United States Roofing Tile Company, at Parkersburg, W. Va., and was devised and worked out by them. In outline the trimmer is about as shown in the following drawing:

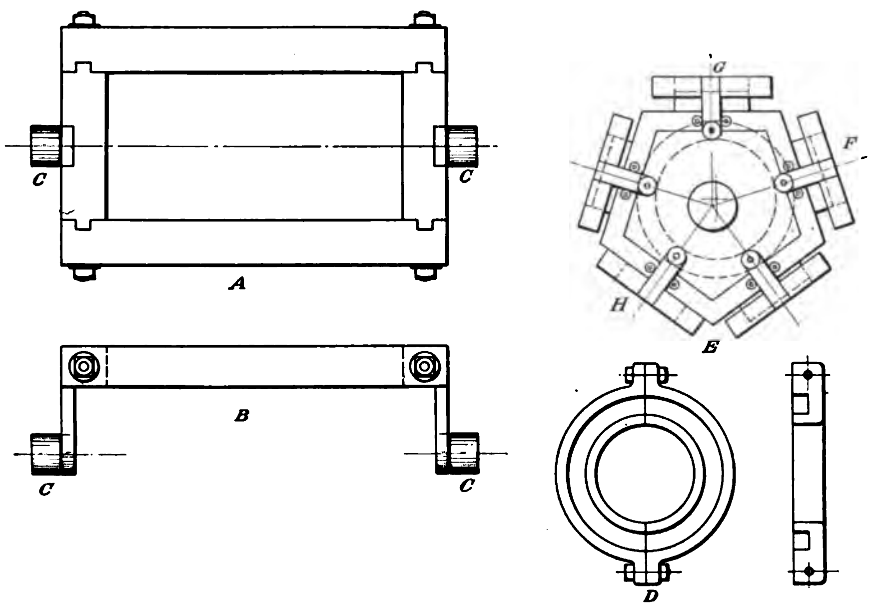


Fig. 79—Tile Trimmer, in Use at the United States Roofing Tile Company.

The trimmer consists of two parts, the frames A and the track D. A represents a top view of the trimmer. It is nothing more than a steel frame made to encase the die. At the two ends of the frame are shown rollers, C. The side view B of the frame shows the position of the rollers in reference to the frame; they are attached by lugs projecting downward.

D represents the track, in which the rollers of the frame work. At E is shown an end view of the press pentagon with the five dies and trimmers attached. The track as indicated by the dotted line is placed out of center with the pentagon, being highest at the upper and feeding

side of the press. The track of course is attached to the side frames of the press, and does not move.

The operation of the trimmer is as follows: The blank of clay used to make the tile is fed into the die at F. The trimmer at this point is nearly at its full height. The pentagon revolves to G, and the trimmer is at its highest point. The top die comes down, entering the trimmer-frame by a very tight fit and the pressure is made. The top die then lifts and the pentagon turns. When the die has reached H, it will be seen that the trimmer is drawn back to the full depth of the die, thus releasing the tile which is caught on the pallet. The fact that the trimmer has held the edges of the clay in while under pressure, and while moving downward it has smoothed the sides, makes it possible to produce tiles that do not need trimming.

Much could be done along this line that would be of great benefit to the industry.

PATENTS ON ROOFING TILE MACHINERY.

The records of the Patent Office show that great quantities of machines have been devised and patented. Few have become of more than temporary importance. For the convenience of others who are looking up this subject, the following list has been prepared, of the patents taken out on roofing tile machines.

Date of Issue.	Name of Inventor.	Serial Number.	Remarks.
June 12 1855	G. Graessle .... Address not given.	13,059	Dies attached to endless chains, and made to pass between rollers for the neccessary pressure.
Dec. 29 1868	P. A. Brown.......... Indianapolis, Ind.	85,362	Die boxes or frames in which the tiles are formed. Pressure applied by levers.
April 13 1869	Charles Messenger .... Cleveland, Ohio.	88,795	Design of a pentagon press to be operated by hand; pressure being delivered through levers. Probably the first design of a pentagon press in the United States.
Aug. 2 1870	John B. Hughes....... Terre Haute, Ind.	106,062	A table and frame in combination with die boxes upon which tin and muslin were used to prevent the clay from sticking. Pressure applied by levers.
Aug. 23 1870	Joseph Christen ...... New Orleans, La.	106,550	Design for a pentagon press; a better design than that of No. 88,795.
Jan. 10 1871	John Koehler .... Warren, Ohio.	110,859	A roller having the die or one face of the tile impression attached. The other half of die with its clay charge was pushed under the roller, thus receiving the imprint. A very poor machine for the work.
June 27 1871	John B. Hughes....... Terre Haute, Ind.	116,447	Similar to No. 110,859, though more practical.
Aug. 27 1872	Calvin J. Merril .... Upper Alton, Ill.	130,856	Dies for diamond tiles attached to segments of rollers, which in turn are revolved through a short arc bringing the dies together.
Sept. 9 1873	Calvin J. Merril....... Upper Alton, Ill.	142,576	Dies attached to large rollers or wheels which press the dies together as they revolve.
Mar. 13 1877	Jacob Greenawalt ..... Pittsburgh, Pa.	188,291	Design of a press having a three-sided die holder instead of the usual pentagon. Tiles to be delivered onto a belt beneath the press. Design is of doubtful value.

Date of Issue.	Name of Inventor.	Serial Number.	Remarks.
Dec. 4 1877	Horace B. Camp ...... Cuyahoga Falls, O.	197,718	Design of a press having a horizontal revolving table to carry the dies under a plunger for the pressure. For some classes of roofing tile work this press would be of value.
Dec. 23 1884	Carl Schlickeysen ..... Berlin, Germany.	309,568	An after cutter and former for auger-made interlocking tiles.
April 5 1892	John E. Donaldson ... Montezuma, Ind.	472,189	Design for a metal tile die.
Dec. 13 1892	George H. Babcock.... Plainfield, N. J.	488,049	Design of a press upon which the dies are brought together as a pair of jaws. This press was for several years in use at Alfred,N.Y.
Mar. 14 1893	Wilhelm Ludowici..... Jockgrim, Germany.	493,366	Design for a pentagon press. The pressure is applied by power through eccentric-shafts. This design shows the spider and trip wheel for dumping the dies.
Jan. 23 1894	Joseph Rapp .... New Philadelphia, O.	513,140	Design of a machine or cutter for cutting auger-made Spanish tiles.
April 14 1896	Karl Thomann........ Halle, Germany.	558,326	A hand press better adapted to cement tiles than those of clay.
Dec. 22 1896	Gustav Krebs......... Halle-on-the-Salle. Abraham Weil, Steinheim, Germany.	573,604	A complicated hand press; would be better for cement than clay.
June 15 1897	Franz Kunzemann .... Eilenburg, Germany.	584,374	Design of a pressing table for molding tiles in dies by hand in connection with tamping and scraping arms. Would probably be of more service for cement than clay tiles.
Jan. 18 1898	Abraham Weil .... Steinheim, Germany.	597,447	Hand press for forming tiles, very complicated.
July 26 1898	John C. Merrill........ Alfred, N. Y.	607,870	A press having a horizontal die table which carries the dies under the plunger. Was originally designed for the manufacture of dry pressed tiles.

Date of Issue.	Name of Inventor.	Serial Number.	Remarks.
Dec. 6 1898	A. B. Klay, G. Jennings and F. Ewing....... West Cairo, Ohio.	615,560	Toggle joint press, for description, see Fig. No. 71, page 258
Mar. 7 1899	Carl H. D. Wicke ..... Lehe, Germany.	620,817	Hand press for forming cement tiles.
April 10 1900	Abraham Weil .... Steinheim, Germany.	647,431	A drop or hand tamping press for cement tiles.
Oct. 2 1900	Richard Lesch .... Bruno Polte .... Konstadt, Germany.	658,791	A machine consisting of a roller die under which pass the opposite dies moved by endless chains.
Mar. 12 1901	Wilhelm Ludowici..... Jockgrim, Germany.	669,535	Improvement on trip and escapement wheel of pentagon presses.
Nov. 26 1901	Abraham B. Klay .... Ottawa, Ohio.	687,688	Toggle joint press illustrated and described in Fig. No. 71. An improvement over patent No. 615,560.
Aug. 12 1902	Xavier P. Gilardoni ... Choisy-Le-Roi, France	706,926	Design of a pentagon press for making hollow interlocking tiles.
Mar. 22 1904	Louis Strenli.......... Zurich, Germany.	755,253	Design of a revolving horizontal table press for cement tiles.
May 31 1904	John W. Campbell .... Colorado Springs, Col.	761,201	A screw press and die for making cement tiles.
Nov. 7 1905	William P. Meeker ..... Newark, N. J.	803,700	Mold or casing for making tiles by hand.
Nov. 14 1905	Henry Meyer .... Warren, Ohio.	804,753	Dies or forms for making cement tiles.
Nov. 21 1905	Alfred Gaspary .... Markranstadt near Leipsic, Germany.	804,944	Outfit for making cement tiles.
Nov. 13 1906	Alfred Gaspary .... Markranstadt near Leipsic, Germany.	835,858	An improvement on patent 804,944.
July 30 1907	Samuel A. Jones ...... Deshler. Ohio.	....	Hand press with die forms for making cement tiles.
Oct. 13 1908	William Pugh......... Streator, Ill.	900,778	A die frame or box over which a roller is passed to press the material, cement or clay, into the proper form.

NOTES ON THE MANUFACTURING OPERATION.

The foregoing descriptions have set forth more or less superficially the types of machinery used in the preparing of blanks for roofing tiles and for actually making the tiles and finishing them. In applying the machinery to the different shapes of tiles, a great variety of practice was found, of which it is the intent to give a resume.

The Forming of Shingle Tiles.—The use of shingle tiles has made its greatest development in Germany, and naturally its greatest development in its method of manufacture has there occurred.

As shown in Chapter II, there are many forms of shingle tiles. The plainest and simplest are merely the flat slabs of burnt clay, usually three-eighths of an inch or one-half inch in thickness, by five or six inches in width, and twelve to fifteen inches in length. They may be made with ribs, lugs, interlocking features, ornamented and grooved surfaces, etc. The more complicated they are made, the less distinction remains between them and the regular interlocking tiles.

Plain Tiles vs. Lugged Tiles.—Plain shingle tiles may be fastened to the roof by two nails, driven through perforations made when the tiles are soft, or by hanging the tiles by lugs on their under surface, which hook over the edges of the roof purlins. The former method is in use almost exclusively in America, while the lugs are the usual method in European countries.

There are several points in favor of each method. Taking up the lug method first, the following points may be made:

First. Nails are dispensed with. It is claimed that nails will in the course of a few years rust off, allowing the tiles to slide down off the roof.

Second. It is difficult to insert new tiles on roofs that are nailed on. It is impossible to raise the tiles that are in place sufficiently to allow putting in new ones. With lugged tiles, it is only necessary to push the new tiles up under the old ones, until the lug catches over the purlin.

Third. Tiles with lugs are less apt to break when on the roof than nailed ones. In nailing tiles it frequently happens that the roofer drives the nails down too tight on the tiles. This lifts the outer ends, and puts the tiles under a strain, so that it takes only a slight jar or a load applied to the outer end of the tiles to break them. In the case of the lug tiles, each one hangs loose and free, thereby allowing for expansion and contraction and for irregular loading, as in walking on the roof while under erection or in the process of cleaning, removing snow, etc.

In favor of nailing shingle tiles in place the following reasons may be brought out:

First. For siding purposes the nailed tiles have the advantage; in fact, lugged tiles cannot be used for this purpose unless other provision than the lug is made to hold them in place.

Second. In manufacture the lugged tiles are somewhat more complicated than the nailed tile. In the lugged tiles it is necessary to provide special cutters to remove that part of the rib of clay along the back of the tiles that is not needed for the lug. The Germans, in particular, have in use many excellent cutters for this class of work.

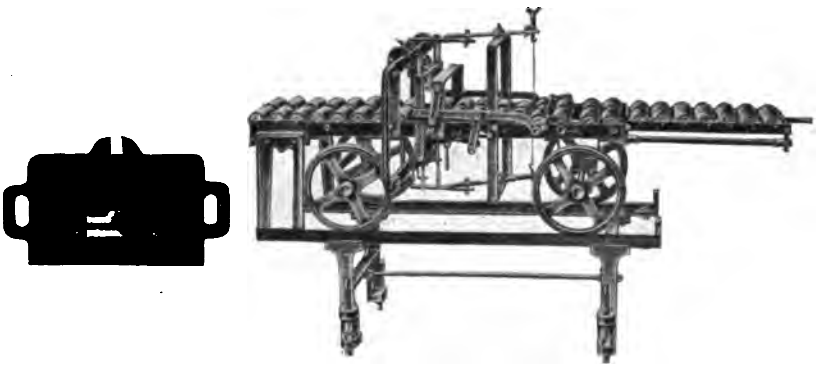


Fig. 80—Single Stream "Beaver Tail" Shingle Tile Die and Cutter, made by Th. Groke, Merseburg, Germany.

They not only have cutters that will take care of a single bar of clay, but cutters that will handle two bars of clay with two tiles to each bar.

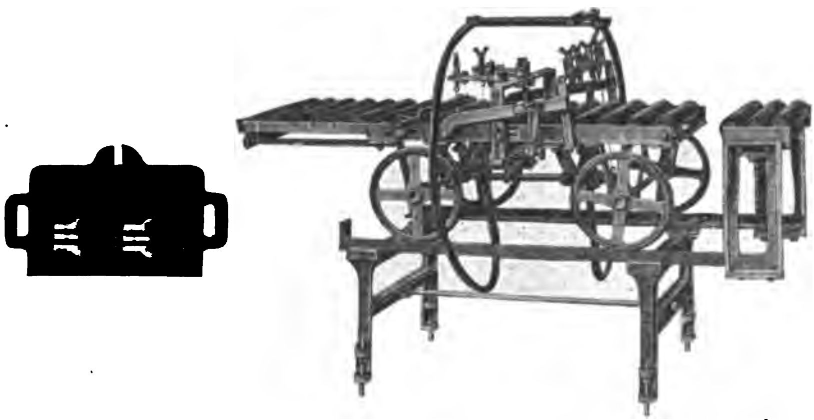


Fig. 81—Quadruple Stream "Beaver Tail" Shingle Tile Die and Cutter, made by Th. Groke, Merseburg, Germany.

Third. Tiles with lugs require more clay than nailed tiles. In a plant producing twelve thousand shingle tiles per day, from five hundred to eight hundred pounds more clay will be used making tiles with lugs than would be required in making the straight bar. This extra material takes up a proportionately increased amount of heat in drying

and burning. This item is not of serious weight, but its effect is adverse to the lugged tile.

Fourth. Tiles with lugs are more troublesome to handle in the setting of the kiln and at other points, on account of the fact that every other tile must be reversed in order to allow them to nest tightly.

It can be seen from the above that each shape has its shortcomings. The American tile manufacturer seems to be very much in favor of the plain shingle tiles with nail holes. Not a single instance of the manufacture of shingle tiles with lugs was to be found in this country in 1908. It would seem, though, that the manufacture of lugged shingle tiles, could be profitably taken up by our factories. This style of tiles would unquestionably meet the approval of the architects, and at the same time would be gladly accepted by the roofers as soon as they found that a roof could be covered in much less time. Of course the roof would have to be stripped with purlins, but these would not require one-tenth of the amount of nailing that a complete covering of tiles would require.

As to the cost of manufacture, it is believed that lugged tiles can be made as cheaply as the ordinary hand-punched kind if cutters of proper design are employed.

Popularity in United States.—In the United States, the manufacture of shingle tiles is not very extensive. There were only two plants working exclusively on this style of tiles in 1908. Nearly all of the other roofing tiles plants also make shingle tiles, but they are only an unimportant side line in most of them. Hence at the above two plants, where the entire output is of shingle tiles, it is natural to expect to find their manufacture developed to a much better degree than in those plants where only a few are made.

The manufacture of shingle tiles has given more trouble to the roofing tile manufacturers than all other styles combined. At first thought it would seem that the simplicity of shape and the small size of the tiles would decrease the difficulties of manufacture, but the reverse has proved true. It is doubtful whether there is in the entire clay industry any ware more difficult to produce with good degree of mechanical perfection at the proper degree of vitrification than a plain, simple shingle tile. The fact that it is plain is what makes it a hard problem. To keep it perfectly straight and true during the drying and burning is the trouble. It will be found that tiles with reversed curves, like the Spanish or interlocking forms, are much easier to hold straight, owing to the curves acting as braces on the ribs to prevent warping. In the plain shingle tiles there is nothing to prevent their warping like a green board exposed to the sun.

Then, too, the shingle tiles are very prone to a trouble known as "side checking." These are cracks proceeding in from the edges of the tile

about one or two inches. Also, the shingle tiles are the most apt of all kinds to "centermark" during the burning.

The side checks are due very largely to faulty die construction; that is, the clay along the sides of the tile does not receive the same pressure, while passing through the die, that the central portion of the tile does; hence the two portions are of different density, and will shrink at a different rate, producing cracks. Even if no difference in density can be found, the difference in pressure results in a difference in speed of flow. The bar of clay is like a stream whose current is swiftest in the center and slower along the banks, where it is retarded by friction. If the center of the clay bar flows even one-eighth of an inch faster in twelve inches than the sides, this difference is likely to result in cracks aggregating one-eighth of an inch in width. But the crack also leads to the bar tearing and ruffling up so that no smoothing down by hand or otherwise will eradicate the defects thus initiated.

Methods of setting and burning also play a large part in side-checking shingle tiles. As a rule, in the endeavor to set them so they cannot warp or twist they are set too tight for the heat to penetrate them rapidly, and are then burned altogether too fast. This means that a compact mass of tiles will act about as a solid block of clay would do. The exterior of the pile, receiving the heat first and longest, will shrink and vitrify more than the central parts, resulting in side checks. This point, however, will be treated more fully under the heading of methods of setting tiles.

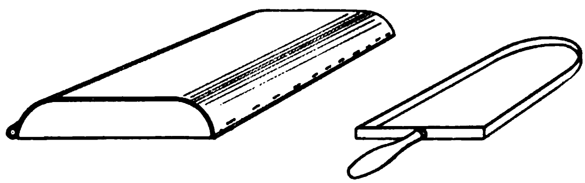


Fig. 82—Hand Mold for Shingle Tiles.

Early Modes of Manufacture.—In the beginning, shingle tiles were no doubt roughly formed by the hands upon a flat area of bare ground, or upon flat stones. Following this, it would only be natural for man to carve out of wood molds or possibly molds of burnt clay, into which he could press the soft clay, and at this state of development, the industry must have stood for many centuries. With the discovery and use of cast iron, the use of this metal for dies naturally entered the field, and still remains an important, but not exclusive, material.

Hand Pressing in Marginal Ring.—In figure 82 will be seen an outfit still in use in many of the smaller plants in Europe. It consists of two parts, first, a piece of plank, over which is spread a piece of canvas or other cloth. This cloth as shown, is tacked along one edge of the block, and is spread upon the surface, covering it completely. It is

is held smooth and taut by an iron rod B, which is sewed into the margin of the cloth, like a curtain pole. The second part of the outfit is the iron frame C. This frame is made with the inside shape and dimensions of the desired tile in the green condition. This frame is placed on the canvas surface of the block, and the previously prepared clay is batted into the iron frame by the hand or by a wooden paddle or "batter," until all parts of the frame are filled. A straight edge or stick or metal scraper is then drawn over the top surface of the clay, cutting it down to the level of the sides of the frame, which thus controls the thickness of the tile produced. A board or pallet of about the same outline as the tile, is now held upon the surface of the clay, which is usually well smeared with a fine red-burning sand. The iron marginal frame is now raised until free from the tile and the tile is "delivered" on the pallet by placing the right hand on the pallet and raising the free edge of the canvas and thus upsetting the slab of clay. The bottom side is then sanded and the pallet carried out to the yard to dry in the sun and wind.

Hand Pressing in Plaster Dies.—Another method for making shingle tiles by hand employs moulds made of plaster of Paris.

These moulds are made in one piece, so that after pressing and pounding or "batting" the clay into the mould, and scraping off the excess, much as in the case of the preceding method, the clay must remain in the mould for possibly an hour to allow the moisture to be absorbed by the plaster mould and the clay to shrink loose from it. Each workman must, therefore, be provided with enough moulds to keep him busy for an hour or more, i. e., enough to enable him to work continuously.

The above methods are of course very crude, and would prove impracticable in this country with our expensive labor, unless it might be on some special order, where genuine hand-made tiles are desired and the price paid is sufficient to warrant making them after this old-fashioned manner. Such cases do arise, and with increasing frequency, as architects give more attention to the reproduction of old types of buildings.

Shingle Tiles by Hand Power Presses.—While it is possible to make shingle tiles on hand presses as perfectly as on any other, very few if any are made in that manner in this country. In foreign countries, where labor is cheaper, some forms of shingle tiles are still made on the hand-power press, but in the nature of the case, since the shingle tile is the easiest form to make by expression through flow dies, very little work is now done by hand-power presses except for odd pieces, such as miter tiles, valley tiles, gable, and sometimes tower tiles.

Shingle Tiles Manufactured by Flow Dies.—It can safely be said, that at least ninety per cent. of all shingle tiles are now made by this

method. The general simplicity of outline of this variety of tiles would indicate its adaption to this method of manufacture. Shingle tiles, as made in this country, are cut from a ribbon or thin flat bar of clay, usually three-eighths to one-half inch thick by five to six inches wide, in lengths of twelve to fifteen inches. The types of machinery used have been discussed earlier in this chapter.

Shingle Tiles by Plunger Machines.—The sole plant using this method of manufacture in 1908, the Cincinnati Roofing Tile and Terra Cotta Company, of Winton Place, Cincinnati, Ohio, has been described with care in connection with the plunger machine and will not receive further consideration here.

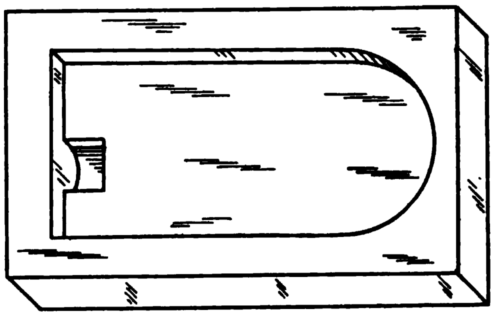


Fig. 83—Plaster Mold for Shingle Tile.

Shingle Tiles by Auger Machines.—As the only two plants occupied solely in shingle tile manufacture are both using the auger machine, it follows that the larger part of the shingles in this country are produced by this method. These plants are the Huntington (W. Va.) Roofing Tile Company, the oldest, and the Murray Roofing Tile Company, of Cloverport, Ky.

The dies through which the tile bar is extruded, constitute really the only critical or characteristic feature of an auger machine for roofing tile purposes:

Shingle Tile Dies.—Much attention has been given to the matter of shingle tile dies by the various roofing tile manufacturers, each in turn having devised a die that in their estimation is the acme of success. They usually guard the details of their die with much secrecy. It is questionable, however, whether this policy is a profitable one.

Without doubt, each die in successful operation has its points of excellence, and represents an asset to the company using it, but to any other concern, with clay of different physical properties, it is quite unlikely that it would prove satisfactory. . Hence, by an open discussion and comparison of notes on this point, much valuable information could be given and received, and each concern would be established more safely with a knowledge of the principles rather than of unassorted facts.

The Cincinnati Shingle Tile Die.—The shingle tile die in use by the Cincinnati Roofing Tile and Terra Cotta Company is a duplicate of their Spanish tile die (see Figure No. 98) with the exception of the form of the tile. Hence a description is unnecessary at this point.

Fig. 84—Mueller Shingle Tile Die.

The Mueller Shingle Die.—From the illustration it can be seen that the die is a very simple one, nothing more than a plain casting with the necessary opening for the clay. The corners are belled or coned out as shown, to increase the flow of clay at those points. There is a serious objection to this style of die, that is, the die cannot be closed in as it wears away. Thus in a short time the entire die must be discarded, while if made in halves, it could be closed in and made to do service much longer.

The Parkersburg Die.—The die in use by the United States Roofing Tile Company at Parkersburg, W. Va., is one devised by themselves.

By reference to Figure No. 86 it will be seen that it consists of two parts, a head plate for the auger machine, and the die proper. The head plate is made with friction bosses to hold back the flow of the clay

at the center of the tile, while the corners or edges of the die in the head are rounded out to allow a greater flow of clay to enter these parts. The real opening through the head plate is somewhat larger than the mouth

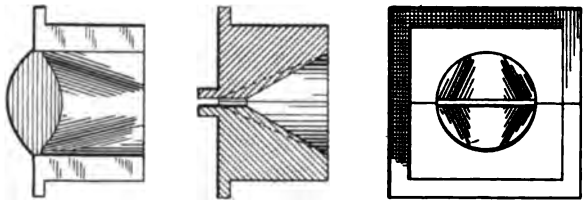


Fig. 85—The Múrray Shingle Tile Die.

piece that is attached by bolts to its face. The mouth piece is made in two parts, to permit closing in as the die wears away.

It will be found in the constructing of a die for running tiles, that provision must be made to restrict the flow of clay at the center of the

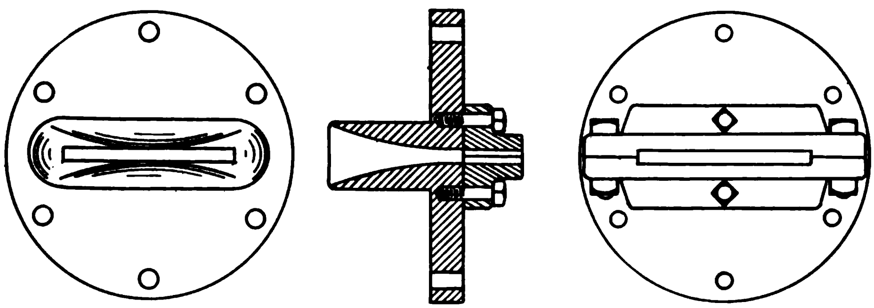


Fig. 86—Shingle Tile Die used by United States Roofing Tile Company.

tiles, and to facilitate it at the sides. The extent to which this will be necessary will vary with different clays.

Another style of die that was for a long time used at the plant of the Chicago Roofing and Siding Tile Company, at Ottawa, Ill., and made by H. Brewer & Co., of Tecumseh, Mich., was similar to Figure No. 87. The only essential difference between this die and the one before mentioned is that the former is known as a dry die; that is, no heat or lubricant is applied to facilitate the flow of clay, while in the latter, the use of oil is provided for, making what is known as a wet or lubricating die. By referring to the cut it will be seen that the feed of oil takes place at the edges of the stream of clay and at an opening between the head plate and the mouth piece. This die gave satisfactory results.

It is believed that our manufacturers should make more use of steam heated and lubricated dies than they do, and that less trouble would be encountered from side-checked tiles than now exists.

Shingle Tile Cutters.—The problem of cutting the shingle tile bar as made by the American manufacturer, is much more simple than that of the foreign countries, especially Germany, where it is not only

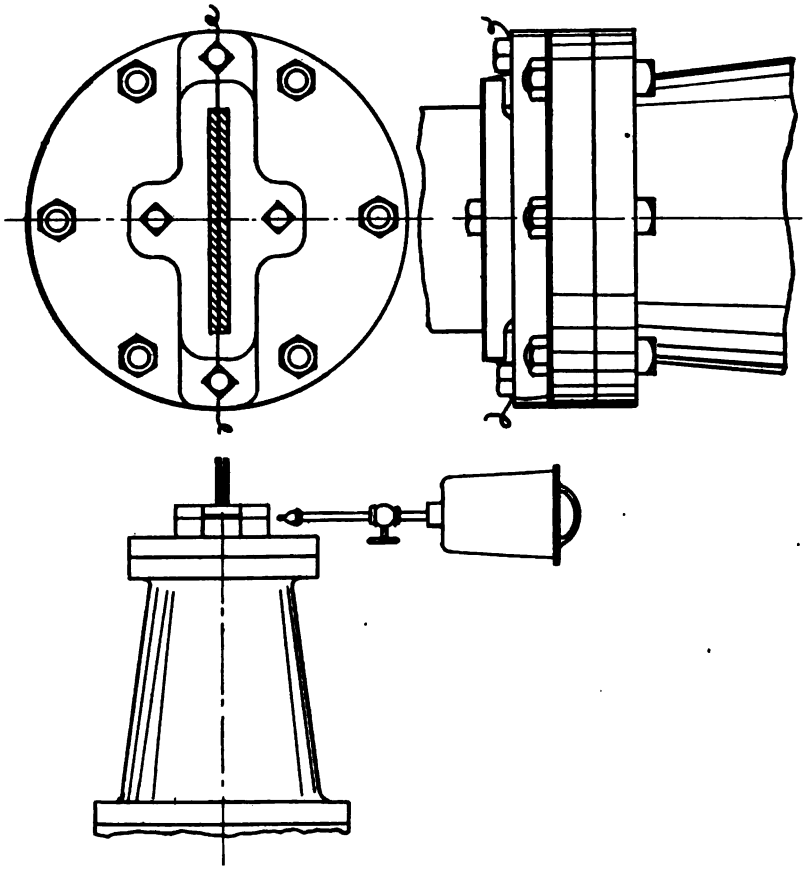


Fig. 87—The Brewer Shingle Tile Die.

necessary to cut off and remove the lug strips from the bar but also to cut the tiles with a rounded end, and as mentioned before, often double or quadruple streams are tó be cut by one movement of the cutter. This feature has been shown in Figure No. 81.

The American auger-machine shingle tiles are run out from the die in single streams only, and are cut with a square or straight end. This simplifies matters very much; all that is necessary to do this is a form of reel cutter. The one most in use is shown in Figure No. 88. It is made by Mueller Bros. of St. Louis, Mo., but is also sold by the Illinois Construction & Supply Co., of St. Louis.

The clay passing over the roller A, causes the reel to revolve. At the ends of the reel arms are stretched the wires, which come in contact

with and sever the tile at B. A pallet is inserted on the endless belt at C. As the tile moves forward on the rollers the front end is caught by the up-coming pallet and as they both move forward the tile is transposed to the pallet. The attention of one person is required to feed in pallets and help to press the tile onto them. The pallet and tile move along on the belt to the off bearer, who places them on a near-by rack car.

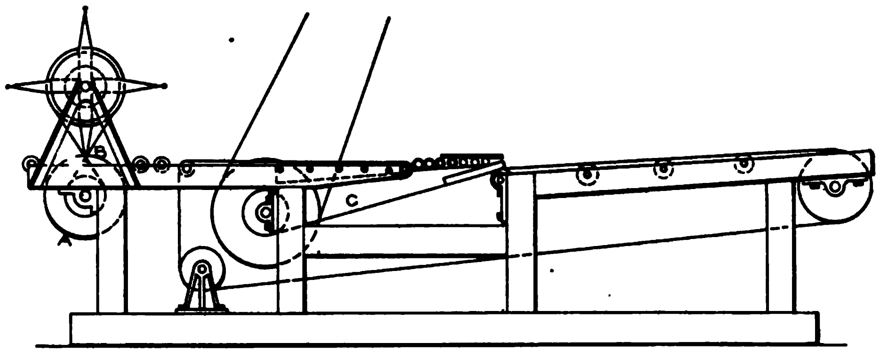


Fig. 88—Mueller's Reel Shingle Tile Cutter, sold by the Illinois Construction & Supply Company, St. Louis, Mo.

This style of cutter is very satisfactory and economical to operate, it being possible to cut and place on pallets with the labor of one man, the entire output of an auger machine, or in the neighborhood of twelve thousand tiles per day.

At the plant of the Ludowici-Celadon Company, New Lexington, Ohio, where a Bonnot auger machine was being used to make shingle tiles, it was noticed that a reel cutter was being used to cut the shingle tiles, but instead of using the system just described to get the tiles onto the pallets, two men were employed with special trowels to take up the tiles from the endless belt, and place them on the pallets.

This method cannot be recommended for several reasons, one being that it requires the labor of two men in the place of one, and secondly, in order to get the trowel under the tiles on the belt, the operator is very apt to mar the ends of the tiles, or possibly start cracks by twisting them or allowing them to bend.

Again, in removing the tiles from the trowel and onto the pallet, he is apt again to bend the tiles or possibly not place them straight on the pallet. In the latter method, however, it is possible to place two or more tiles on the same pallet, while in the case of the self placing system, only one tile can be put on a pallet.

While some of the reel cutters in use were home-made, such firms as the J. D. Fate & Co., Plymouth, Ohio; Mueller Bros., St. Louis, Mo.; and the Illinois Supply & Construction Co., of St. Louis, Mo., have furnished cutters of the type most in use.

Other Methods of Making Shingle Tiles by Flow Dies.—There are a few other methods of manufacturing shingle tiles that have been used with more or less success from time to time in this country, but more frequently in the old world. All of these methods involve running out a bar of some other cross-section than that of a shingle roofing tile slab, and then cutting this bar up lengthwise, as well as crosswise to increase the yield of tiles and decrease the power consumed in expressing a bar of such small cross-section. There are four such processes worth mention.

Splitting a Simple Rectangular Bar.—Only in one instance is this method known to have been successfully carried on in this country. During 1899, the Celadon Terra Cotta Company, of Ottawa, Ill., was producing tiles by running a stream of clay by auger machine through a Brewer die of approximately one inch by six inches cross-section. A fine piano wire was attached to the mouth piece of the die, in such a manner that the clay column was split horizontally into two streams, each being one-half inch thick (see Figure No. 87.) This split stream was then cut into lengths by a home made cutter which worked from side to side of the stream, punching and counter sinking the nail holes in both the upper and lower tiles, as it did so. The two companion tiles were placed on the same pallet and dried together, but just before going to the kiln, they were separated by inserting the blade of a case knife between them.

While this method of producing shingle tiles was cheaper, it was found the tiles did not sell as well as the single stream tiles, owing to their under surface being rough from the wire cut. The tiles were also seemingly somewhat weaker than the regular single stream tiles.

The principle of forming two tiles at once was good. It would seem that its use could well be extended, but it would be better to have the tiles issue from the machine separately, one above the other, thus giving two perfect tile bars, from which tiles with both surfaces finished could be cut. The streams would come together before reaching the cutter, and from there on could be handled as a single tile, thereby saving pallets, dryer and kiln space and labor.

Cutting a Solid Bar Into Several Tiles.—It is not known that this system has been used at all in this country, but in the foreign countries where tiles with lugs are in favor, it has been largely used on account of the cheapness of handling the tiles, and also because it is much easier to hold the tiles straight during the burning by keeping them in the block form.

Figure No. 89 shows the form in which the tiles are run from the auger machine. As the column issues it is cut into lengths suitable for the tiles, usually fifteen inches. The block is passed along to a second cutter, where wires are so arranged that they cut the false ribs, leaving a small portion at one end of each tile to form the lugs by which the tiles are to be hung to the roof. The block of tiles is then taken to the

dryer, and finally burned without separating. It will be readily understood that the portions of the ribs cut away are burned along with the tiles, but upon separating the tiles after burning, these waste strips are easily removed, and can be reground with new clay and used as grog.

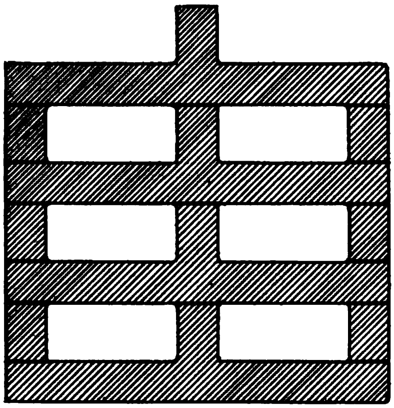


Fig. 89—Roofing Tile Bar in Block Form, with points indicated at which the cuts are made to Divide it into Separate Tiles.

This system of handling shingle tiles is better in some respects than any yet discussed, in that they are handled in large units, and will give less trouble from side checks, owing to the fact that the blocks permit a moderately open yet solid and stable setting, which will not tip or rock easily and will permit the free circulation of the gases. Time being given for the heat to fully penetrate each of these blocks, there will be no side-checking.

By this system center marks on the tiles—that is, dark blue or black spots so often seen in the central area of tiles that have been burned too fast—when set flat or tight will be entirely obviated, because each tile is separated from its neighbor, thus allowing an easy access of oxygen and heat to the central face of the tile.

Under the heading of setting tiles it will be seen that resort to this same method has been had in part by the manufacturers of the ordinary flat shingles in this country to overcome side cracks and center markings.

It is true that fewer tiles can be set in a given kiln space, but the per cent. of firsts will be higher, due to the favorable conditions under which the tiles are dried and burned. Hence, in the long run the output is likely to be larger than in the case of tiles set flat or tight together.

Cutting Hollow Blocks Into Tiles, Horizontal Delivery.—In this system the tiles issue from the machine in the shape of a rectangular column, the sides of which form the tiles, four in number. As the column issues from the die it is cut nearly through by the small steel blades, so arranged that they cut the corners of the column. A small web about an eighth of an inch thick is left to hold the adjoining sides together. It is usually necessary to run the clay rather stiff, to prevent the block from collapsing upon being cut. This cutting is usually done straight down, and not from side to side. After the column has been cut into tile lengths, a wooden form that fits the inside opening is inserted the full length of the newly cut block. The form has a handle attached to it, whereby the off bearer lifts the block from the cutter table, and stands it on end on a pallet either on the floor or a truck. Before removing

the form, the necessary nail holes are punched by hand. The form is then withdrawn, and the block passes on to the dryer and kiln, where it is burned in its original form, that of a hollow block. After burning, the block is given a sharp tap with a hammer, when it collapses, forming four separate tiles. In this system there are no waste strips, or ribs, as in the one previously described. There are, however, some other drawbacks. First, great care in handling must be used, to prevent the collapsing of the hollow block while cutting, punching and moving it to the dryer; second, the blocks are bulky, and much space is lost both in the dryer and in the kiln, though it usually happens that much small stuff, such as hip-rolls, tower tiles and special cuts, can be nested inside the hollow blocks, utilizing much of the otherwise lost space. It is obvious that center marks will not be encountered under this system. Also, there will be less likelihood of side checks than in single tiles, because the corner is the thickest part of the block. Again, tiles burned in this manner are less apt to warp, the tiles being held fast to each other along their edges.

Vertical Delivery.—This method does not differ from the preceding except in the method of delivery.

In Figure No. 90, A represents the auger chamber, or plunger, part of the machine. The clay is first tempered in some other machine, then fed into the chamber A, where it is caught by the plunger, or auger, and forced down through the die. A pallet, B, is placed upon the platform, C, directly under the descending hollow column. As the advancing clay comes in contact with the pallet, the platform, which is delicately counterweighted, moves downward at the same rate of speed as the issue of the clay. After descending a distance sufficient to produce one length of tile, the platform stops, and at the same instant the auger is automatically thrown out of gear, which stops the flow of clay. The cutting wires, D, are a part of the movable platform, so that they are always at the proper level to cut the column of clay into the desired length without waste. At E a shoot, or waster, is made by a wire cutting off the lower end of the pipe next to the pallet. The purpose of this waster is to secure tiles of uniform length if the pallet is uneven or warped or if the lower end of the column of clay becomes upset or marred by too heavy contact with the platform on which it rests. The waste cut also assists in holding the block true during the shrinkage period while drying, serving the same purpose for which sewer pipe manufacturers put rings of wet clay under their pipes. In the case of shingle tile manufacturers, it is usual to remove the waste cut before placing the tiles in the kiln for burning.

This method is, in some respects, better than that of the horizontal delivery. First, the manner in which the form is received, direct upon the pallet without rehandling, is better; second, there is less loss from

collapsing; third, the small waste ring is advantageous in that it tends to prevent the tiles from separating or warping at the lower end upon drying.

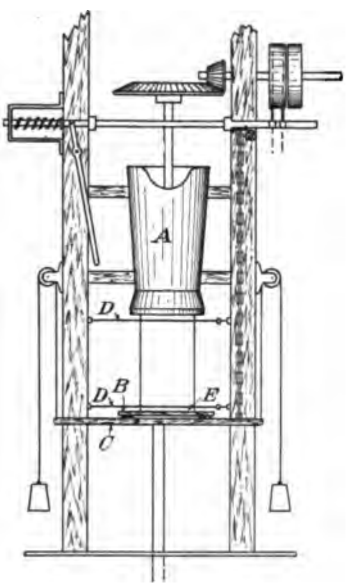


Fig. 90—Vertical Delivery of Shingle Tiles in Block Form.

There is, however, one feature that is possibly not so good as the horizontal delivery, namely, the output will be smaller, owing to the fact that the machinery must be thrown out of gear or stopped at the end of each tile length to allow for the cutting and removal of the tile, while in the horizontal delivery system the issue can be continuous.

In Figure No. 91 it will be seen that the inventor provided a recutting apparatus to cut and remove these parts of the lug strips not needed for the lugs. This he accomplished by making a form carrying four wire cutters substantially as shown in the drawing. This form was inserted in the hollow block, until the block F rested upon the pallet. The handle H was then given a partial turn, so that the arms I engaged with the springs J, which in turn pushed the cutters K outward to a position where they would cut the lug strip free from the tile. Upon withdrawing the form, the severed strips were then removed by hand. In the case of tiles with nail holes, it would only be necessary to insert a form at the upper end a short distance to hold the pipe in shape while punching.

Shingle Tiles by Power Presses.—By the use of a power press it is possible to make many forms of shingle tiles that are impossible to make on the flow die machines. The greatest difference lies, however, more in the matter of ornamentation, or outline of the tiles, than anything else.

The use of auger machinery to run out and cut off the blanks, followed by the power press to give them any desired finish, or lugs, or shape, or ornamentation, therefore constitutes the most modern and effective equipment for shingle or any kind of roofing tiles. Whatever part of the output that can be used in the form in which it comes direct from the auger machine can be so made. Where the trade demands more ornate shapes, the use of a different die and different reel cutter and power press immediately permits this line to be made also.

The best example of the press-made shingle tile is found in the plant of the United States Roofing Tile Company, Parkersburg, W. Va. This company is manufacturing a tile of somewhat unusual shape, being

patterned after the ordinary wooden shingle; i. e., thick at the butt end and tapering down to quite a thin section at the other end. The object of this shape is to allow the tile to fit more closely to the sheathing boards.

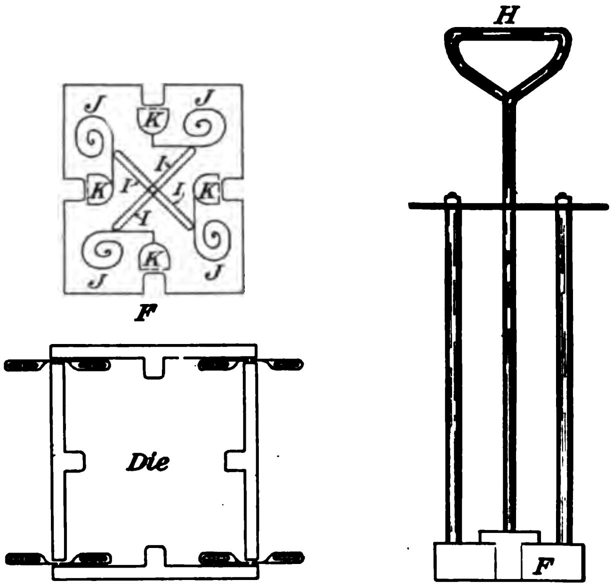


Fig. 91—The Robinski Lug-Cutting Apparatus.

Not only does the tile vary in thickness from end to end, but in some of their patterns, the monotony of an otherwise plain tile is broken by an outline of gutters and raised parts on the portions of the tile which extend from the next superposed tile on the roof. Such shapes exclude any other method of manufacture than that of pressing.

In the manufacture of these tiles, the company first runs blanks on one of J. D. Fate & Co's. combined double shaft pug mill and auger machines. The blanks are about one inch thick by five inches wide and are cut fifteen inches long by a reel cutter.

From the cutter the clay blanks are conveyed by an endless belt conveyor to the presses (see Figure No. 93).

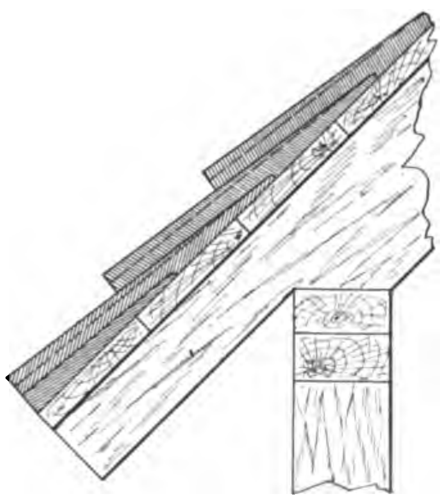


Fig. 92—Pressed Shingle Tiles made by the United States Roofing Tile Co.

Just as the blanks leave the cutter, they are coated or painted on their upper face with an oil especially made for this company by the Upson Soap Company of Parkersburg, W. Va. The oil is applied to prevent the clay from sticking to the metal dies of the press. As the blank reaches a point opposite the press, it is picked up by the press feeder (see Figure No. 94) and fed onto the nearest die of the pentagon on the press. As the pentagon of the press revolves one-fifth revolution, it brings the blank of clay under the top die where it receives a pressure that causes it to flow out and fill every part of the die box, each blank being cut to a length that is just sufficient to exactly make one tile. After the pressure has been applied, the pentagon revolves one-fifth revolution, the tailsman or off-bearer places and holds a receiving pallet on the tile, and as the pentagon moves to its next position, the tile loosens from the die resting on the pallet (see Figure No. 95). The off bearer then places the laden pallet on a rack where the tiles are examined and the nail holes punched by boys. This company is manufacturing three styles of pressed shingle tiles, one form of which is shown in Figure No. 96. Other companies are making various forms of pressed shingle tiles. Among them are the Ludowici-Celadon Company, Mound City Roofing Tile Company, Alfred Clay Company, and the Detroit Roofing Tile Company.

Shingle Tiles by the Dry Press Process.—While this fascinating method of working clay has on several occasions been tried in this country in the manufacture of roofing tiles, it has never yet proved successful. The trouble has been that the tiles could not be made dense enough to withstand the weather. In addition, the roofing tile dies are usually of complex enough shape, so that the dry powder filling the die would have a variable thickness in different parts. On the descent of the plunger, the thick part of the powder layer would be much more densely compressed than in other parts where the clay was thin. Grave irregularities of structure are thus produced, and the process is not practical. By packing the die with the powder in advance of the descent of the plunger, and cutting out the excess clay in the thick parts by hand, it is perfectly feasible to make a tile of irregular cross section and of uniform density, but the cost of hand packing the die for each tile is too great.

If any success is reached, it will be by the use of previously tempered plastic clay, partially dried, granulated, and pressed with enough water in it to make a dense body, which flows under heavy pressure and forms a perfect bond. Such a process is used in electrical porcelain manufacture, and it seems possible that it might be introduced in roofing tile manufacture, especially for the simple forms. Exactness of shape, a great desideratum in roofing tile manufacture, would be secured in the highest degree.

Fig. 93—Cutter and Tile Blanks, United States Roofing Tile Company.

Fig. 94—Feeding Side of the Roofing Tile Press, United States Roofing Tile Company.

THE FORMING OF SPANISH TILES.

The roll tiles in their various forms have been used more widely than any other single style or shape. Among the most ancient tiles, traces of the roll or normal tiles are to be found. Their use has been not only very extensive, but satisfactory from both the artistic and practical point of view.

In the manufacture of this style of tiles in the United States, many improvements in form and methods of manufacture have been made. It is rare to see this style of tiles made in this country in any other manner than by power machinery, while in the old world many are made by hand either in plaster moulds or on hand presses.

Hand Pressing in Plaster Moulds.—In making this shape in hand moulds, it is necessary to have the clay prepared quite soft and well kneaded, with the plaster mould on a low bench or table. The presser takes up a mass of clay sufficiently large to make one tile with a little to spare, and rolls or works it into a "grub" in shape like a loaf of rye bread. This roll is then thrown into the mould with considerable force, and batted by the hand and forearm until it fills every part of the mould. The excess is then scraped off, or cut away by means of a straight-edge or wire-cutter. The necessary lugs or nail holes are made, and the inside is "slicked" with a rubber card or sponge. The mould is then set aside, until the clay shrinks loose from the plaster. The tile is then emptied out onto a pallet, while the mould goes back to the bench to be refilled.

With an ordinary granular clay, not too adhesive, that will give up its water freely to the plaster mould, from ten to twenty moulds will be found sufficient to keep one presser busy, but should the clay be extremely plastic, a much larger number will be required.

This method of manufacture is the most expensive of all, and at the same time the tiles are apt to be weak, because very little pressure can be applied in the manufacture, and the clay is worked very soft and rather lean and sandy.

Pressing in Hand Power Press.—The next method used in the manufacture of Spanish tiles is by hand-power press. While this method is perfectly possible, it is not used at all in this country, at least on regular tiles. Special Spanish tiles, like tower tiles, eave tiles, hips and valleys, etc., are to some extent made on hand presses. In the plant of the Cincinnati Roofing Tile and Terra Cotta Company, all special Spanish tiles are made on a Perfection Hand Press, manufactured by the C. W. Raymond Company, Dayton, Ohio. At the Western Roofing Tile Company, special Spanish tiles were made on a small hand press of the eccentric type. This press had been formerly used in a glass works for pressing glass and had been fitted with new dies for the clay

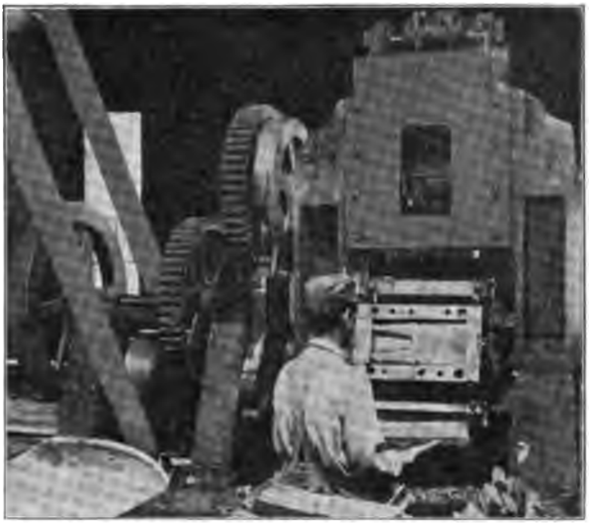


Fig. 95—Off-bearing Side of the Roofing Tile Press, United States Roofing Tile Company.

Fig. 96—Press-made Shingle Tiles, United States Roofing Tile Company.

business. The name of the manufacturer could not be obtained, but it is not important, as the machine is not regularly on the market.

Spanish Tiles by Flow Die Processes.—The simple straight "S" tiles, without lugs or interlocking features, permit the use of flow die methods, and as this method is always cheaper than pressing, it is certain to be used whenever it is available. Both types of flow die machines, plungers and augers are used.

Spanish Tiles by Plunger Machine.—The plunger machine itself has been described to some extent earlier. The only example of the use of this machine for the manufacture of Spanish tiles found in the country in 1908 was seen at the Cincinnati Roofing Tile and Terra Cotta Company, Winton Place, Cincinnati, Ohio.

At this plant, much attention is paid to having the clay well tempered before reaching the plunger machine. It is ground until it passes an eighteen-mesh screen, then enters a storage bin located on the second floor of the building. From the bin, the clay is introduced by spout into a seven-foot wet pan, manufactured by the American Clay Machinery Company.

In the wet pan the clay is tempered with water for a period of ten minutes or so, and is then unloaded onto a belt conveyor which delivers it to a hopper placed above the charging hole of the plunger machine. This hopper will hold about two wet pan charges at a time. A man is stationed at the hopper, where he feeds the proper amount of clay into the machine on each stroke by a shovel. The output of the machine depends upon the feeder, for he can, by overfeeding, cause much waste and loss to occur. In the case of the Spanish tile the amount of clay needed for each tile is, roughly speaking, about an ordinary shovelful, but as the clay is in lumps of more or less irregular size and shape, it is not always possible to feed the proper amount. In order to have a sufficient amount, the feeder feeds what he thinks will be a little more than enough.

The output for this plunger machine, under the most favorable conditions, will not exceed 5,000 Spanish tiles. More often the daily output does not exceed 3,500. With an auger machine and the same number of operatives, these figures can easily be doubled.

Cincinnati Spanish Tile Die.—In Figure No. 98 is shown a line drawing of the Cincinnati Spanish tile die. The drawing on the left represents the outward face of the die, from which the finished tile column issues. On the right is shown the rear or inside face of the die, with the beveled shoulders and the belled or coned corners, each of which is necessary to control the proper flow distribution of the clay.

The sectional drawing more clearly shows the amount of bevel on the main part of the die. The corners, however, receive a slightly greater increase of bevel.

It will be seen that this die is made in two parts, which divide at the extreme edges of the tile, as indicated in the drawing on the face side of the die. The two parts are fitted very carefully together, and are then held in that position by the two bolts, as shown.

When the die wears away, allowing the tile to come too thick, the halves are taken apart, and the points of contact dressed off until the proper thickness is again secured. By this means it is possible to prolong the life of the die very materially.

Ordinarily these dies are made of cast iron, though at times chilled iron and steel have been used. In the latter materials the dies are extremely difficult to dress or file in order to get the proper feed of clay.

Fig. 97—Hand-power Press, Western Roofing Tile Company.

Periodic Cutters.—It will be found very necessary to have a well-constructed and accurate cutter for handling Spanish tiles. At the Cincinnati plant a cutter manufactured by the American Clay Machinery Company is being used.

Figure 99 shows the cutter in detail, except that the angle clippers are not required on the cutter as used at Cincinnati. In operation the cutter works about as follows: As the "S" shaped bar leaves the plunger, it passes over a wool-covered, oily roller, shown in cut, which lubricates the under side of the bar, so that it moves freely over the cutter table without sticking. The bar is allowed to run out until its outer end has passed the second slot shown in the cut. The lever is

then pulled down, the block A comes in contact with the top of the clay column, where it rests, while the two cutting wires pass on down through the clay into the slots. As the wires descend, the bolts, or pins, encircled by springs, descend also, punching the nail holes. The handle is now released, the counterweight raises the cutting frame clear of the tile. The block A remains on the tile until the cutting wires have cleared the clay, then the block moves up out of the way. This is done to prevent the wires, on their return through the clay, from "feathering" the ends of the tile. Immediately at the outer end of the cutter the offbearer stands with a trowel (see Figure 100).

This trowel he inserts under the pan of the tile while on the cutter table, then lightly supporting the roll of the tile with the other hand he lifts the tile from the table and places it on a pallet near by.

The work of offbearing is not only very tiresome, but very exacting as well. Much pains must be taken to see that the tiles are placed on the pallet straight, otherwise they will dry crooked, and must be returned to the dry pan as scrap.

At the Cincinnati plant the tiles are placed three deep on a single pallet. Formerly they were placed five deep, but this was abandoned.

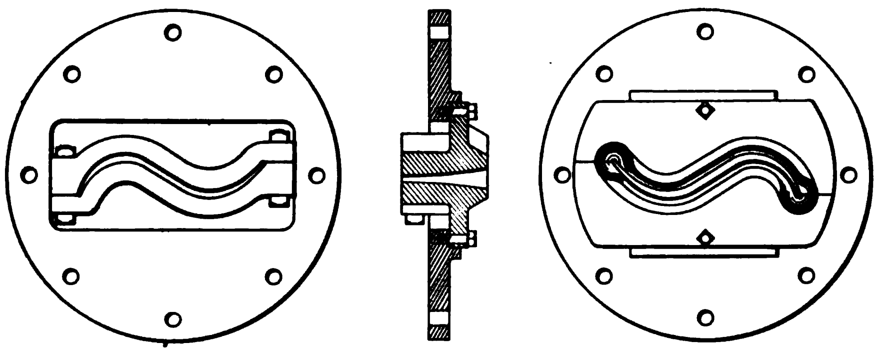


Fig. 98—Spanish Tile Die, Used by the Cincinnati Roofing Tile & Terra Cotta Company.

In Figure 101 can be seen the three tiles on the pallets in place on the truck. The pallets will be discussed under the section on dryer cars and pallets.

Spanish Tiles by Auger Machines.—The manufacture of Spanish tiles on the auger machine differs from that on the plunger machine in that the column of clay moves continuously from the auger, instead of intermittently, as from the plunger. It will be understood that with the moving bar a cutter must be provided that moves with the bar, while with the plunger machine the cutting table remains stationary, and cuts only when the bar is at rest. It would be impossible to make a straight cut through a moving clay bar unless the cutting wires were moving at exactly the same speed as the clay. The backward and for-

ward movement of the cutter does not move to exceed eight or ten inches, because ample time is given to make the vertical cut and return the cutting wires to the original position while the clay bar travels that distance. By a small lever, under control of the operator's foot, the entire table is returned to its original starting point after each cut.

At the plant of the Ludowici-Celadon Company, New Lexington, Ohio, where more auger-machine Spanish tiles are made than at all other American plants combined, it was found that they are using four auger machines of various sizes, the largest one of the four being used on Spanish tile. It is not meant by this that the particular machine in use by them is any better suited to the work than other machines of equal capacity, but it indicates the strength and power required to force clay out from so small and so irregular an aperture. The Ludowici-Celadon Company is using wooden pallets, as shown in the figure, and also places tiles three deep on one pallet. Their cutter is of their own design. In general it is not widely different from the American Clay

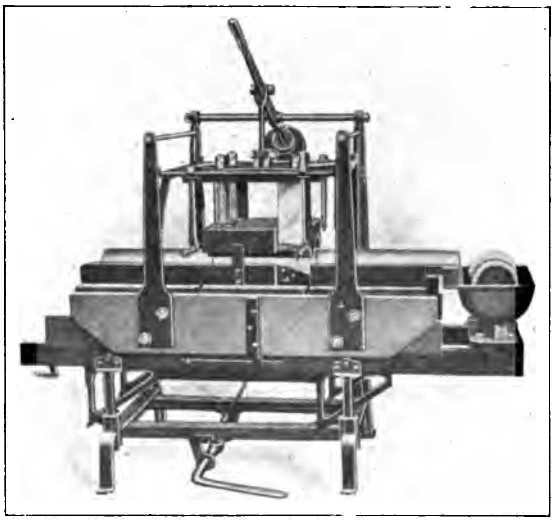


Fig. 99—Spanish Tile Cutter, by the American Clay Machinery Company.

Machinery Company's cutter (Figure No. 99), except that it is much stronger and is movable. The cutting wires pass through the tile with a downward shearing motion instead of straight down.

Spanish Tiles by Power Presses.—At the present time there is only one type of press in use for the manufacture of regular Spanish tile—namely, the revolving pentagon press.

Revolving Table Press.—A number of years ago, at Ottawa, Ill., a press of the revolving horizontal table type was used for making small-sized Spanish tiles. This press was manufactured by D. J. C. Arnold,

of New London, Ohio. Metal dies were used on this press, lubricated by a light oil applied by hand. Blanks were first made on an auger machine. These were fed, one at a time, onto the dies of the revolving table. In due time the blank came under the upper die, where it received the necessary pressure to shape the tile. The table in its next move brought the die with its newly pressed tile to the "dumper," who placed a pallet upon the tile with one hand, and turned the die half over, or until the tile loosened and dropped onto the pallet. The dies were hinged at one side to permit of dumping. To operate the press under the conditions at Ottawa three men and a boy were required—a press man, oiler boy, feeder and dumper. The daily output was from thirty-five hundred to five thousand.

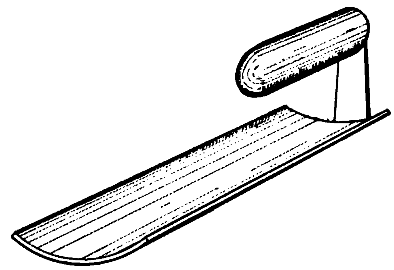


Fig. 100—Trowel Used for Removing Spanish Tile from Cutter.

This press was not a success, economically, the output being too small for the number of men employed. If it were improved by supplying an automatic dumping device and automatic oiler, it would probably be thoroughly practical and satisfactory.

There is a class of work that could be done on it cheaper than by the ordinary drop presses used on special work.

The Pentagon Press.—Five different presses of this type were found in use for the manufacture of interlocking Spanish tiles: at the Western Roofing Tile Company, one press manufactured by Crawford & McCrimmon, Brazil, Ind.; at the Detroit Roofing Tile Company, one press, manufactured by the Illinois Supply & Construction Co., St. Louis, Mo.; at the Ludowici-Celadon plants, Chicago Heights and Ludowici, Ga., presses manufactured for them in Chicago, copied from the Ludowici tile press of Germany; at the Ludowici-Celadon Company's plant, New Lexington, Ohio, presses manufactured by the Rogers Machine Tool Company, of Alfred, N. Y.

In three of the above plants, plaster dies were being used. In the other two cast iron.

The methods employed by the various plants in the production of press-made Spanish tiles are the same, with the exception of the lubrication of the metal dies.

The first step is that of producing the blank from which the tile is to be made. In every one of the above plants this is done by auger machines. The J. D. Fate Company, of Plymouth, Ohio, has five double-shaft combined pug mill and auger machines at work on Spanish blanks, and the Bonnot Company of Canton, Ohio, has one.

Neither of these companies claim that its press or auger machine is specially or exclusively for the production of Spanish tiles. They use the same machinery on any and all of the styles of tiles they produce. For instance, The Detroit Roofing Tile Company is making six or seven styles and sizes of tiles on a single press, it being customary to run a good stock of one kind of tiles, and then change the dies and run another style. Similarly in the production of blanks of Spanish tiles, the auger machine must make blanks for all kinds and oftentimes prepare the clay for the modeling floor as well. The clay coming from the pug mill or other tempering device, or if it has been aged after the tempering, coming from the cellar, is fed into the auger machine, which forces it through the mouth piece in a bar of the desired shape. In the case of the Spanish tile blanks, it is usual to have a double stream die, with two columns issuing from the machine at the same time. These streams are usually about two and one-half inches by four inches in cross section, with rounded corners. Upon leaving the die they pass under a reel cutter, which cuts the two bars into lengths of about twelve inches, which will furnish a slight excess of clay over that needed for a single tile.

As the blanks pass from the cutter, they are carried by an endless belt to the pressman or feeder. Immediately behind the feeder or a little to one side, is a low bench, upon which a boy "hacks" the blanks as they are delivered by the belt. It is usual to keep a stock of fifty to one hundred blanks on the bench at all times, to tide over short stops of the auger machine. Before commencing work it is necessary to see that the plaster dies are well saturated with water. This being done, the feeder takes up a blank with both hands and slams it with considerable force onto the face of the die in front of him. The pentagon, making one-fifth revolution, brings this newly filled die under the top die, which descends, forcing the blank to fill all parts of the space between the top and bottom dies and squeezing out all excess clay. The pentagon again moves, the off-taker or tailsman places a pallet upon the tile, and waits for the die to reach the third position, when the tile releases very easily.

The pallet (see Figure No. 153) with its tile is then put on a belt conveyor driven from the pentagon shaft in such a manner that it moves forward about two feet with each movement of the pentagon. Thus, between intervals, the edges of the tiles are "skinned," or trimmed by boys or girls, one on either side of the belt. It is usual to have another known as the "puncher" whose duty it is to punch the nail holes, or to perforate the small lug on the under side of the tiles by which they are wired to the roof purlins. Another boy or man is required to take the tiles from the belt after they have been trimmed and put them into the dryer cars.

Fig. 101—Plunger Machine Making Spanish Tiles, at Cincinnati Roofing Tile & Terra Cotta Co.

Fig. 102—Tiles Delivering from Press. Detroit Roofing Tile Company.

The output of Spanish tiles on a pentagon press will run from four thousand to six thousand per day. The latter figure can seldom be attained.

Lubrication of Dies.—Where metal dies are used for Spanish tiles, it is necessary to keep the dies hot to assist the clay in releasing. This is done in one plant by steam, which passes directly through the backing of the die. At another natural gas flames were used, the flames coming in direct contact with the face of the dies. The oil used for lubrication was the Atlas press oil, made by the Standard Oil Company.

Where steam was used to heat the dies, the oil is sprayed onto the dies by compressed air. In the other plant the under side of the blank was oiled by passing over a wool-covered roller, which was dipped in oil. Instead of oiling the upper face of the blank the oil was applied to the top die itself by hand.

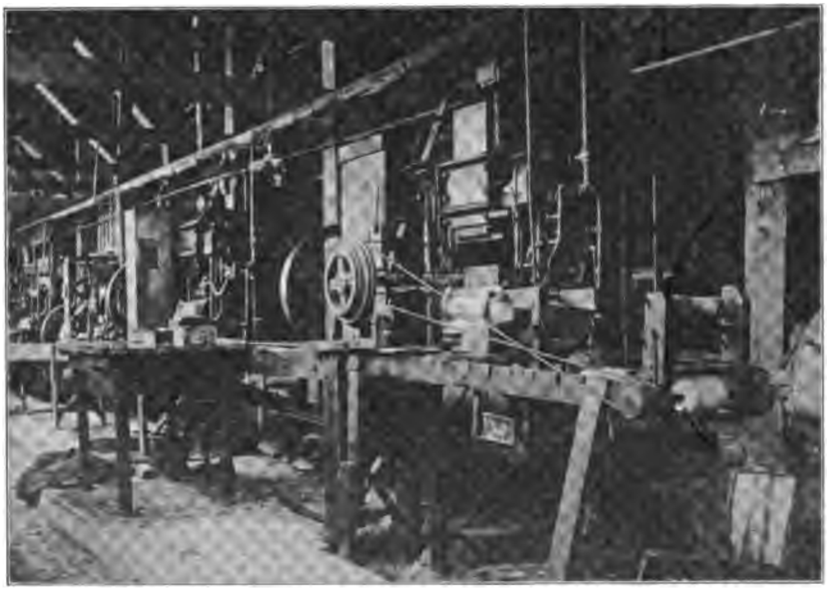


Fig. 103—Home-made Reel Cutter for Cutting Blanks. Ludowici-Celadon Co., Alfred, N. Y.

FORMING OF INTERLOCKING TILES.

The interlocking tiles in this section refer to the regular interlocking tiles of commerce, such as those known as the French A, T-1, D-1, etc., manufactured by such firms as the Ludowici-Celadon Company, The Mound City Roofing Tile Company, The Detroit Roofing Tile Company, The National Roofing Tile Company, The Alfred Clay Company and others. It must also be understood that these same companies manufacture interlocking tiles of both the shingle and Spanish varieties, and various other patterns already discussed. These forms of interlocking tiles are becoming the most widely manufactured

at the present time in this country, if not in the world. This is due to the universal use to which they can be put; that is, they can be applied on almost any kind of roof construction, such as open or closed construction, either wooden or steel. They are considered the cheapest tiles to manufacture per square, on account of their large size, can be sold at the lowest price, and are the cheapest to apply. Hence, it is easy to see why they are so popular. With the use of proper principles in designing the locks they also make one of the best roofs.

The methods of manufacture in the various plants are but slightly different. In every case the blanks are made on auger machines, which are undoubtedly the most efficient for this work. Of the various auger machines found in use for this work, there were six plants using Fate machines, one plant using a Bonnot machine, and two using the American Clay Machinery Company's machines.

Shape of Blanks.—As to the shape of the blank, six of the plants are running bars of about two and one-half inches by four inches, which are then cut into suitable lengths, about fifteen inches, by reel cutters of the type to be seen in Figure No. 103.

These bars are made both in single stream and double stream dies. There is something to be said for the double stream die here, which perhaps does not apply with equal force where it is expected to use the bar after cutting as a finished product, viz.: the die pressure is much less, and the power required to run the auger machine is materially decreased. Since the blank undergoes a complete rearrangement in pressing, any faulty structure, if any exists due to double stream dies, is eliminated. On the same reasoning a side-cut brick die and cutter could be used equally well, with still less die pressure, but no instance of this was found. It is possible that the wire-cut surface of the side-cut brick might still persist in some degree after pressing, which of course would not do.

At two plants the blanks are run with outlines conforming to those of the tiles to be made. The blanks have the side-tongues and grooves, and the press then only has to form the head and heel locks.

As to the relative merits of shaped vs. unshaped blanks, it can be said that where plaster dies are used, the thick two and one-half inch by four inch block form is the better. The die fills better if the clay has to flow vigorously, than if the blank is nearly shaped in advance, and changes shape but little in pressing. Also, the tiles seem to release from the die with less trouble where the clay flows, than when fed in pre-shaped blanks.

In the case where metal dies are used, the reverse is certainly true. With metal dies, oil must be used to prevent the clay from sticking. If the clay has to flow vigorously under pressure in the die, it will scour the oil from the metal, leaving the surface bare in the central part, where the flow has been longest kept up. The tile will then stick

in the center. Also, the oil that has been pushed along ahead of the clay enters the tongue grooves, and prevents the clay from properly filling them.

It will thus be seen that it is better to run the blanks for metal dies of approximately the same outline as the finished tile, leaving the work of the press as light as possible.

The mere forming of the end locks does not cause any extensive motion of the main part of the clay and hence the oil is not disturbed, and still acts as a separating medium between the metal and the clay. Each form of blank therefore has its proper place, depending on the kind of die used. There is one objection, however, to the plan of running blanks of a shape to conform to the tiles, viz., it is not possible to store very many of them in advance owing to their thin section and the ease with which they dry out and are broken. This requires the auger machine to run almost continuously to supply the blanks as needed.

In the case of the simple rectangular blank, large numbers of them can be piled up ahead of the press consumption, thus making it possible to change dies on the auger machine and run other kinds of ware a part of the time. In plants of moderate size, this latter point will be found of considerable weight.

Pressing.—The pressing of the interlocking tiles is not different in any but the most trivial details from the pressing of such tiles as have already been discussed, and no further time need be spent on it at this point.

Forming Interlocking Tiles on the Auger Machine.—There is a great field for the introduction of interlocking tiles made on the auger machine in this country, which is not receiving as yet any attention. Not a single plant in this country is making tiles of this kind at the present time, and only one instance was found where work along this line had been done in the past.

Just why our tile manufacturers have not taken to the auger-made interlocking tiles can only be surmised. Foreign roofing tile makers have for many years seen the possibilities of the auger machine on this class of goods, and have perfected many ingenious devices in the matter of dies and cutting tables to properly form the bar and cut it into interlocking tiles.

In the nature of the case, it is only possible to run the locks along two parallel sides of the bar. If side locks were made by the flow die, the end locks cannot be made, and *vice versa*. It is quite probable that the lack of end locks has been the objectionable feature of auger-made interlocking tiles which has prevented their adoption in this country. This objection has weight, of course, but not more weight than it has in the case of auger-machine Spanish tiles, so popular at the present time.

By laying such tiles on closed-roof construction, with roofing proper beneath, they can be made to give satisfaction. No one would think of applying the auger-machine Spanish tiles on an open construction roof, i. e., on purlins only; neither should anyone think of so doing with the auger-machine interlocking tiles. The auger-machine interlocking tiles provide a cheap material for cheap structures, a field that is only occupied at present by the culls of the other styles of tiles. Any one undertaking to enter a cheap auger-machine interlocking tile into the field of the pressed variety would unquestionably fail in his attempt.

The firm that at one time made interlocking tiles on the auger machine was the Ludowici Celadon Company, at their New Lexington plant. The tiles as manufactured by them were of such a cross section that the under side of one tile would fit the lines of the upper side of the next below.

One style of auger-machine interlocking tiles does provide a partial head lock. These tiles are made from a rectangular pipe, the two interior faces of which are separated by some little space. After the bar has been cut into lengths, as shingle tiles are cut, it passes to a second cutter, which notches out the ends of the tiles as shown in the cut below.

These notches allow the lower end of the upper tile to lap over the upper end of the lower tile, thus making a partial lock.

Plaster Dies vs. Metal Dies.—The first use of plaster of Paris for roofing tile dies dates far back into the past. It is doubtful whether any material will ever be found to supplant it. At least on most clays it is the only material that will give a perfect tile. Metals of various kinds have been tried, and are being used at the present time, but no single case has yet been seen where tiles made on metal dies are free from flaws and checks due to the necessary use of some kind of lubricating oil. With tiles from plaster dies, this cannot be said.

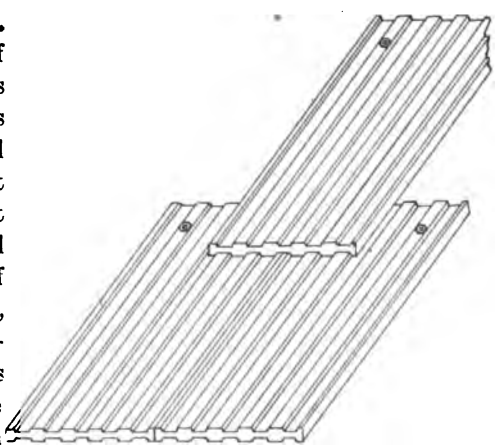


Fig. 104—New Lexington Auger-made Interlocking Tiles.

By analyzing the conditions in the two cases, it will be clearly understood why the above is true. 1st, with plaster dies, it is necessary to work the clay softer than with metal dies; 2nd, plaster dies are necessarily kept saturated with water. With metal dies, their surface must be oiled with a heavy oil. When a blank is fed onto either kind of die,

and the pressure is applied, the blank is squeezed very quickly down to the thickness of the finished tile. In undergoing such a radical change of shape, many small checks and seams will infallibly develop. On the plaster die, which is saturated with water, the water will find its way to these newly developed checks, softening their edges and helping them to mend or unite while under pressure. In the case of the metal dies, the oil used for lubrication will enter the checks just as the water does with plaster dies, but instead of assisting them to knit, they are prevented from doing so. There may be certain clays, high in free silica, which would prove an exception, but for fat, plastic clays, such as roofing tiles are usually made from, the above certainly holds true. The fat clays work much the best on plaster dies. Another fact comes into consideration in this connection, viz., the clay must be in a markedly more plastic condition for forming on plaster dies than for metal. This assists powerfully in preventing as well as in mending checks or flaws.

On metal dies, the stiffer the clay can be worked, the better it will release from the die, but the more numerous the checks will be. It is true that metal dies are being used with more or less success on some clays. What the properties of a clay are which determine whether it can be successfully worked on metal dies or not has never been satisfactorily worked out.

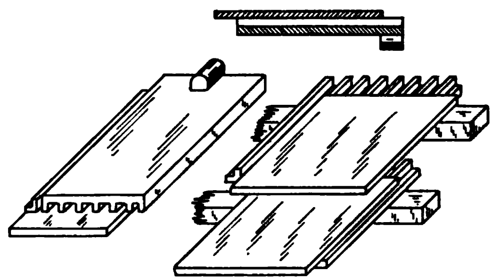


Fig. 105—Auger-made Interlocking Tile.

Roughly speaking, the more plastic, fine-grained clays, low in gritty substances, are best suited to plaster dies, while clays of the opposite physical properties are best suited for metal dies. The strongest objection to plaster dies is that they are expensive to keep in repair. It is necessary on most clays to renew them every day. Top dies are often renewed twice per day.

To keep this work up requires the work of one man and a helper in a five-press plant. The same workman, however, also makes all the plaster dies needed about the plant, such as crestings, hip-rolls, copings and special pieces. Every roofing tile establishment has to be able to meet calls for these ornamental pieces, and at least one plaster worker is a necessity, anyhow.

The plaster of Paris used should be of a good grade, and should be very finely ground for the best results. The average price per barrel of suitable plaster is from $2.25 to $2.10, or often less when bought in carload lots.

Making Plaster Dies.—The art of making plaster dies for roofing tiles is by no means a simple thing. Much experience is required to work the plaster so that when cast the resultant dies will not be full of air-blebs, known to the trade as "rat holes." If blebs appear on the surface or in the body of the die, the plaster will have to be chipped out and the casting remade.

To make the die, three parts are required, the upper and lower die shells and the tile matrix.

The shells are cast iron boxes, made to conform roughly to the shape of the tile. They are made about one-half inch longer and wider on each end and side than the tile. and about three-fourths inch deeper than the thickness of the tile. The thickness of the iron in the shells is usually about three-eighths to five-eighths of an inch on the sides and three-fourths of an inch for the bottom.

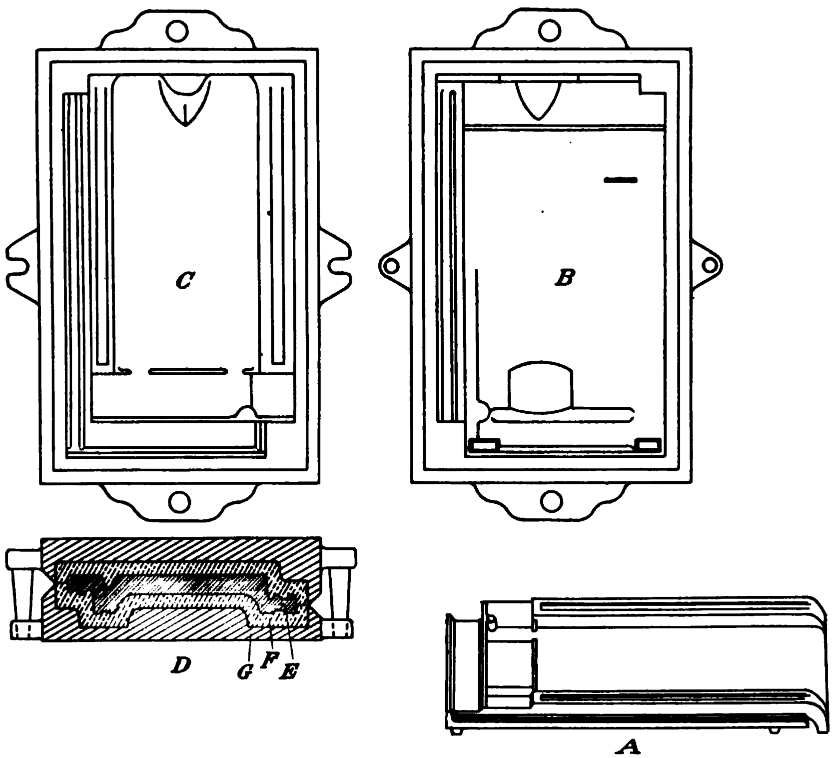


Fig. 106—Die Shells and Matrix for Making Plaster Dies.

In Figure No. 106, A represents the matrix of the tile. This matrix is an exact pattern of the tile to be made. It is usually made of cast iron—though aluminium is better—and is finished off perfectly smooth and to size, with dividing lines on the sides and ends to mark the depth to which the matrix is to be set in the die shell when casting new dies.

B and C represent the upper and lower die shells, with the plaster in place. D shows a cross section of the dies when pressed together. E represents the clay necessary to form the tile, shown by the heavy shading. F represents the plaster facing of the die, and G the cast iron die shells. Assuming that the new die shells are to be lined with plaster, the steps to be taken are as follows:

First. Swing or adjust the matrix to its proper level in one of the die shells. This is done by blocking it up on small pieces of wood to about the proper level, and then adjusting it by small pats of clay on the top of the wooden blocks. The matrix is then tapped with a mallet until it takes a good bearing and is on the right level.

Second. The space surrounding the matrix and separating it from the shell is now filled in with plastic clay. When filled, it is carefully smoothed and finished so that it coincides with the line of the matrix.

Third. The upper surface of the matrix is now painted or coated with a dressing called "dope," composed, as a rule, of soap and some sort of fat, preferably lard, boiled in water to a creamy consistency. In some cases paraffin dissolved in kerosene oil is used. Each plaster worker has his own preparation, which he thinks is best. One receipt runs:

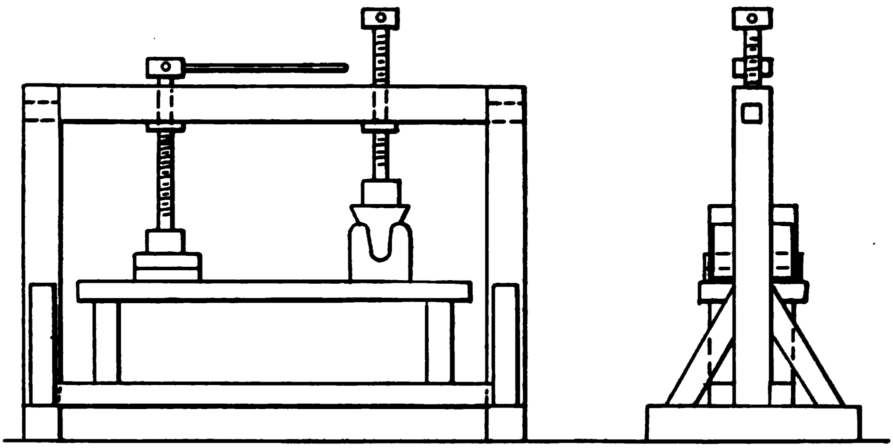


Fig. 107—Press for Plaster Dies.

For four pounds of soft soap, boiled in four gallons of water, add one pound of tallow, and stir thoroughly. In any case the function of this dressing is to keep the plaster from adhering to the surface of the matrix. It is always of a greasy nature, but the use of a greasy soap solution seems usually preferable to the use of oils direct. This dressing is applied to the matrix face, and rubbed off until it has just a thin film left upon it.

Fourth. Preparation of the plaster is next. Should the die require one pailful of plaster, take between one-third and one-half pail of soft

tepid water, and sprinkle handfuls after handfuls of loose, fluffy plaster, free from lumps, into the water. This must be done somewhat slowly—not much faster than it will sink beneath the surface of the water. Continue to sift plaster with the hand into the water until the plaster appears to build up in a cone above the surface and only a narrow ring of water is showing around the edges of the cone. This is allowed to stand for a few moments, sometimes for several minutes. The plaster and water are now to be worked and stirred with the hand, first seeing to it that all parts of the mixture are free from lumps. By a peculiar twist of the hand and forearm, the plaster can be made to boil up, so to speak, from the bottom of the pail to the top. This working of the plaster allows entrapped air to escape, and must on no account be done in such a way as to churn more air into the mixture. The stirring continues until by the feeling of increasing density, or viscosity, and also of warmth, the plaster worker knows that it is time to cast.

Fifth. Carefully coat the surface of the matrix with a layer of plaster to the depth of about one-half inch. Be very careful not to entrap any air bubbles on the face of the matrix under the plaster. The balance of the plaster is now poured into the empty upper die shell. At the moment when the plaster assumes sufficient set so that it will not fall out of the shell, the upper shell is turned over onto the lower one. Then slip the two cases under a screw press, and bring a pressure to bear until the two shells meet at their parting lines. The excess plaster escapes. In ten or fifteen minutes the screw is released, and the dies taken out and separated. It usually happens that the matrix will adhere to the newly made die. If so, it is gently loosened, but not removed.

Sixth. The lower shell is now cleaned of the clay used to hold the tile matrix in position, and is placed ready for its charge of plaster. The matrix and the exposed parts of the newly made upper die are now coated with "dope." Another pail of plaster is prepared, and the work repeated. When taken from the screw press, the shells are opened, and the matrix is carefully removed from the last made die.

Seventh. The dies are now allowed to stand for some time—a half day if possible—and then, before using, they are placed in a tank of water and allowed to soak up all the water possible. This takes ten or fifteen minutes, sometimes more, depending on the hardness of the plaster.

The hardness and strength of the cast die varies with the density of the plaster or in other words with the lack of porosity, produced by working all the plaster possible into a given quantity of water. Plaster made up with the minimum of water consistent with full hydration and application is called "strong" plaster and is relatively dense. When as much water is used as will permit the plaster to set, a spongy soft cast is obtained and is called "weak." Both kinds have their particular

field. For instance, in dies, it is desired to have a die that will stand wear or abrasion, and it is not necessary for the plaster to absorb much water. Therefore, in dies, the plaster should be strong. At times it has been recommended to use lime water, that is, calcium hydrate solution, in the working of the plaster dies, to harden them. Shellac or gum, as used in stucco work, has also been tried, but the hardening of the die must not be carried too far, or the clay will stick to it instead of releasing as it will from a die of moderate hardness.

For plaster molds to be used in hand pressing, it is desirable to have the water absorb water from the clay rapidly. Hence, the plaster is worked with more water, producing a relatively weak or porous mould. The foregoing process represents the common one in use in renewing plaster dies.

Fig. 108—Press for Plaster Dies at Detroit Roofing Tile Company, Showing Mold in Position.

Iron Master Moulds.—A better process for the renewing of worn out plaster dies is to use master dies or moulds of iron or steel, from which the real dies are made. A master die or mould is the cast or impression taken from a die with a tile in it. With dies thus made of both the

upper and lower surface of the tile, it is only necessary to spread plaster on the face of the master die, fill the empty die shell and press the two together, instead of having to build up the empty die shell with blocks of wood and clay and to adjust a loose matrix in position each time. The use of master dies is to be strongly recommended, not only from the economy in labor, but because more accurate and better dies can be made.

CHAPTER VI.

THE MANUFACTURE OF SPECIAL SHAPES AND ROOFING TERRA COTTA.

In no other line of structural clay ware manufacture is so great a variety of shapes required as in the roofing tile industry, excepting the manufacture of building terra cotta. In the latter, the use of stock patterns is very limited, and the manufacturer expects to make a complete set of moulds for each separate job he undertakes. As all of the decorative work of a building in which terra cotta is used is usually executed in this material, the number of special moulds which are made to be used once only is extraordinarily large.

While the body of any tiled roof is covered with stock tiles of one shape, there are nevertheless an endless variety of shapes to make for trimmings and for adjustments between different parts of a complex roof, and these have to be in various sizes and various pitches to fit the angle of the roofs. Then, too, the roofing tile manufacturer is called upon to cover towers of every conceivable size and outline, so that the outlay for dies and moulds represents an important part of his necessary investment and one which is never completed. As long as he is in the business, so long will his stock of moulds and dies grow. It is of course impossible to describe all of this ever changing medley of shapes and sizes. There are, however, certain kinds of fittings that are very commonly needed and these will be taken up one by one.

Hip and Valley Tiles.—The only style of roof which does not require either hip or valley tiles, or both, is the perfectly simple variety, composed of two rectangular planes intersecting at a straight ridge-line, and finished at the ends with gables. All other roofs must have tiles specially cut to fit the angle of the hips or the valleys. In most instances this cutting is done at the plant, while the tiles are still in the green condition. In rare instances, with soft tiles, especially of the shingle pattern, the burnt tiles are cut at the roof, as slate is done.

It will be understood that where there is a hip or valley to fit with tiles, it has two sides and therefore requires "right and left" hip or valley tiles. The number of lineal feet of hips and valleys that has to be cut in covering an average dwelling house roof runs into a hundred or more. Hence each roofing tile plant makes provision for executing this kind of work rapidly, though in some of the smaller plants the work is not done as cheaply as it could be by having the proper facilities. The work is charged for by the running foot, in addition to the usual cost

per square for the tiles. The method pursued at the best equipped plants is to have a "laying out floor," usually on the second floor of the building. The angle of the hip or valley is obtained from the plans furnished by the architect. All orders at modern roofing tile factories in this country are executed from plans for each separate job, and not by selling tiles by the square, or thousand, to be applied by the purchaser to suit himself. It is very unusual to sell from stock, unless for small and very simple orders.

After obtaining the angle from the plans, a base line is struck on the laying out floor to represent the eave line of the building. The length of the rafter is then measured off at right angles to the base line, a nail or spike being driven into the floor at the apex or end of the rafter, and also at the point on the base line from which the rafter was measured.

A protractor with its straight-edge set at the given angle is now moved along the base line, either to the right or left, as the case may be, to a point where a taut line fastened to the nail at the upper end of the rafter coincides with its straight edge. A nail is driven into the base line at this point, and a line is stretched from this point to the top of the rafter, high enough above the floor to allow tiles to slip in under it without touching or moving it. Taking tiles which have stiffened somewhat till they have reached the "leather-hard" condition, the cutter proceeds, beginning at the base line and the intersection of the hips, to lay up a section of tile roof. Each tile is laid on the floor, as it would be on the roof, and under the stretched line. It will be found that the line will cut each tile in a different place, until after a number have been passed one is found which is cut in the same position as the first. This is known as a "repeat," and recurs on a certain number of courses, depending upon the angle. Sometimes the repeat will begin on the sixth course, and again it may not occur until the twentieth or even more. Of course the next tile succeeding the first "repeat" is a duplicate of the second tile, and so on until another "repeat" occurs. When a "repeat" is found, it matters not whether the hip or valley is forty or a hundred and forty feet long, it is only necessary to measure how many feet of the hip are covered by the distance from one repeat to the next, and then to divide this amount into the total length of the hip to be covered, and to cut the necessary number of sets of "repeats." The tiles are cut along the line by a sharp knife, and as they are taken up from the floor, they are numbered as to their position in the set, and marked "right" or "left" as the case may be.

With one set of tiles properly cut for the angle as a pattern, it only becomes necessary to make from lath a set of angles which will coincide with the cuts on the pattern tiles. Then with a stock of leather-hard tiles and a thin-bladed case knife, the cutter can prepare and number the required number of pieces of each sort, for as many sets as are needed. In case hip tiles are being cut, the lower end of the tile only

is saved; if valley tiles, the upper end. It often happens, however, whe e there are hips and valleys in the same roof, that one cutting can be made to serve both, by saving each end of the cut tile. In this case they should be cut only part way through, and burned as one piece and then broken apart.

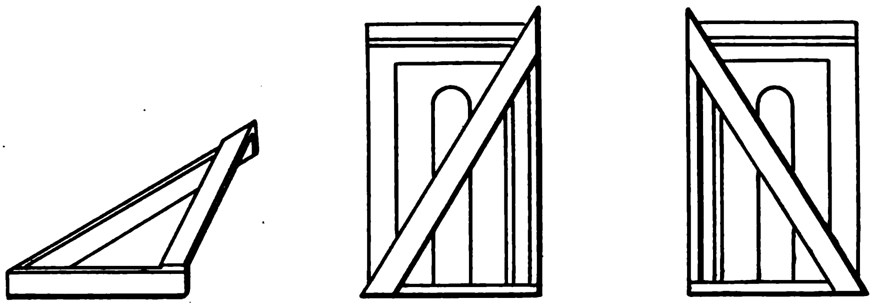


Fig. 109—Angle Frames for Cutting Hip and Valley Tiles.

As before stated, some of the larger and more up-to-date firms have other and better means for doing this work. At the plant of the Detroit Roofing Tile Company, they employ an outfit shown in the following illustration:

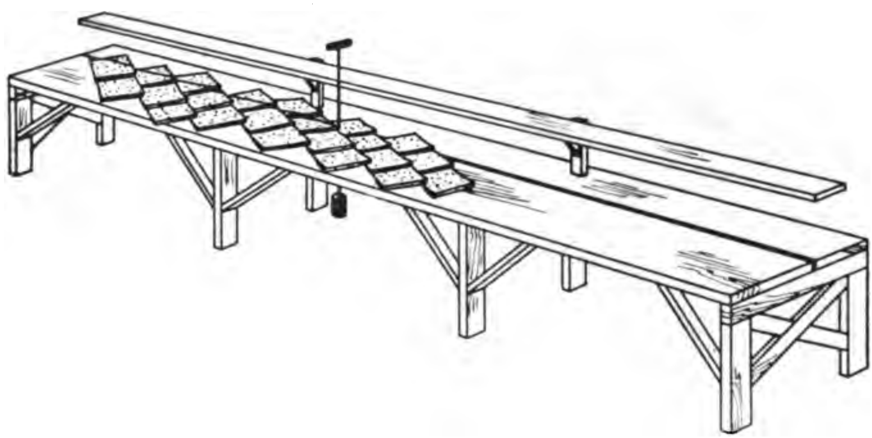


Fig .110—Perspective View of Hip and Valley Cutting Table, Detroit Roofing Tile Company, Detroit, Mich.

This table is made of planks, and is about thirty feet long. Extending along the back side, shown clearly in the end view, is a guide rail, raised about fifteen inches from the table top. Directly parallel with this guide rail, and cutting through the table top for its entire length, is a narrow slot, through which a piano wire passes, with a weight attached to its lower end, and a wooden handle at its upper end. A number of one-inch by two-inch cleats are provided, shown under the tiles on the top view of the table. The slot in the table top represents

the axis of the hip or valley to be cut. The cleats are tacked onto the table top at the proper angle to represent the purlins of the roof.

In operation, a string of green tiles is placed in proper position along and over the slot as though it were on the roof. Should the hip line be twenty-five feet long, the string of tiles is made of that length. The operator then gets up on a walk at the back edge of the table, and grasping the wire by its handle, he raises the weight from the floor, thus bringing the wire under tension. He then proceeds to move along the walk, allowing the wire to drag along the edge of the guide rail from one end of the table to the other, cutting the tiles as it goes. After the tiles are once placed in position on the table, it only takes a minute or less to cut the entire lot. If cut by hand, as described earlier in this chapter, it would require an hour or two to do the same with much more likelihood of making errors.

The cleats representing the purlins of the roof are changed from time to time, as the angle of the hip or valley may require. In cutting rights after lefts, the direction of the cleats is reversed.

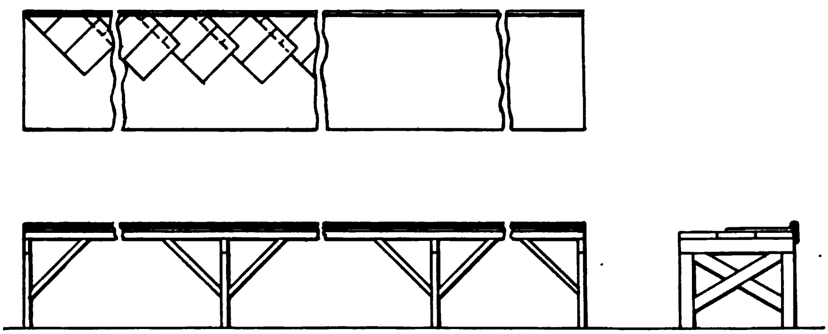


Fig. 111—Table for "Closing" Hip and Valley Tiles, Detroit Roofing Tile Company, Detroit, Mich.

"Closed" Hip and Valley Tiles.—It very frequently happens that it is desirable to have the cut ends of hip and valley tiles closed to prevent the snow and rain from blowing back underneath the tiles. This work, as in the case of cutting ordinary hip and valley tiles, is charged for by the running foot. Before a hip or valley tile can be made with a closed end, it has to first be cut to the proper angle as though it were to be used in the regular way. The ends then may be closed by plates of clay welded on by hand, or by an arrangement for closing a large number at once. The Detroit Roofing Tile Company has in use a table of about the same dimensions as their cutting table; the top is solid and is provided with a facing-board along one edge, which extends up at right angles to the top to a height of three or four inches, depending upon the tiles to be operated upon.

The tiles previously cut to the proper angle on the cutting table are placed in turn in their proper order upon the closing table, the cut end being placed against the back board, as shown in the illustration. The tiles are laid face up for hip tiles and face down for valley tiles. The operator then takes a scarfing tool and proceeds to roughen a strip of the face of the tiles about three-fourths of an inch wide next to the backing board. He then slushes the newly roughened surface with water or clay slip, to make the surface weld easily. A long strip or roll of clay of the proper temper is then placed against the backing board and brought into contact with the prepared ends of the tiles, and welded under pressure of the fingers. The entire table full of tiles is done at once, and as if it were a single tile. After smoothing up the work the operator carefully cuts the backing strip between each two tiles, disengages them from each other, trims and smooths the lower surface of the joints; the tiles are then placed on pallets ready to go to the dryer. Each tile is given its designating number and letter, as well as the order number, so that it may be identified on its way through the plant and at the roof when ready for application.

Much of this kind of work is still done in the slow and costly hand-mould process, in which moulds cut to the proper angle are used, upon which the tiles are placed one at a time and filled or closed by hand labor entirely.

Ridge and Eave Tiles—Most tiles, such as the various forms of Spanish and interlocking, require a special starting tile at the eave line, and a finishing tile at the ridge, to make a proper appearing and a well fitting roof. Spanish tiles, for instance, if left open at the bottom, provide a series of holes or openings which are speedily utilized by birds, bats and vermin in which to build nests, and which also give rains a chance to beat in.

In the Orient advantage has been taken of these closed eave tiles to apply decorations in the shape of fancy ends, or "out looks."

In our country, the closing of eave tiles has been treated as merely a business necessity, and no attention has been paid to using this feature for any decorative purpose, though rich ornamentation can well be used. The architects of this country have thus far overlooked this opportunity, but if they make a demand for fancy eave starters, which can at the same time be made to serve as snow guards, the manufacturers will surely meet it.

The greater part of closed eave tiles are made either upon hand presses or the power pentagon press, using plaster dies. In some of the smaller plants, machine-made tiles are dropped into plaster moulds and the ends put in by hand, but this method is far too slow.

The Cincinnati Roofing Tile and Terra Cotta Company, has devised an eave closer, as shown in Figure No. 115. It is nothing more than a small separate piece of tiling, made to insert under the hollow of the

Fig. 112—"Closed" Hip Tiles.

Fig. 113—"Closed" Valley Tiles.

Fig. 114—"Closed" Eave Tiles.

Fig. 115—Cincinnati Roofing Tile Company's Closure for Eave Tiles.

eave tile, and tacked in position with nails. While this closer can be set back under the tile far enough to give a strong shadow line, its use cannot be recommended, on account of the method of fastening. It is nailed to an eave strip, which extends with the eave line and under the first row of tiles. It is only a matter of time until the nail heads rust or corrode away and the end piece falls out and is broken and the roof is left open.

Ridge or "top" tiles are the same as regular tiles, except the upper half is flattened to a plane, which rests upon the sheathing boards, and is in turn covered by the cresting or ornamental finishing tiles. These flattened tiles leave no openings to be filled with cement, as would be necessary if ordinary tiles were used. In other patterns a flange is attached to the upper end of the tile (see Figure No. 116).

These tiles, like the eave starters, are made largely by hand presses, but in some cases by the power presses. A press that is used on this class of work is that of the Illinois Supply and Construction Company, of St. Louis, Mo. (See Figure No. 72 for description.) The Raymond Perfection hand press has also been used largely on this class of work. (See Figure No. 120.)

With shingle tiles, the cutting of hip and valley tiles is quite often done at the roof by the roofer, it not being much more trouble to cut them than it is to cut slate. Top and bottom tiles are, however, cut at the plant, the former being six inch by nine and one-half inches and the latter six inch by seven and one-half inches. These sizes are cut by the reel cutter, so that extra charge is not made for them.

Hip Rolls and Cresting.—To properly cover a roof and have all parts weather proof, it is necessary to make shaped pieces curved or otherwise to fit over the ridges and hips. These forms are called crestings or ridgings, and hip rolls. The forms of these coverings can be made very plain or highly ornamental, as shown in the following illustration:

It will be seen that many of the cresting forms must be made to fit the pitch of the roof, while others will fit any angle or pitch. The same is true of the hip rolls.

There are many forms of hip rolls that are made by hand in plaster moulds. Each plant, as a rule, has one man that models all new designs and then makes the working moulds for the pressers.

The clay used in this pressing or "terra cotta work" is usually specially prepared; that is, it is pugged by itself to a much softer condition than the regular clay for the machines, and in clays that have a high shrinkage it is very often diluted by "grog" or "grit." This material is made of broken and cull burnt tiles and kiln waste, ground and screened to about the same fineness as the rest of the clay. The amount used is from twenty-five to fifty per cent. This mixture, after being thoroughly pugged, is carried or conveyed to the pressing

floor, where it is stored in bins holding from one to two weeks' supply and kept well covered and frequently sprinkled with water to prevent drying out on the surface.

Fig. 116—Ridge or "Top" Tiles.

The operation of pressing in plaster moulds has been described before, and is substantially the same for wares of all sorts. A good presser will turn out in the neighborhood of 100 pieces of ordinary hip roll per day, but the more complicated ones take more time. It requires from six to twelve moulds to keep a presser busy.

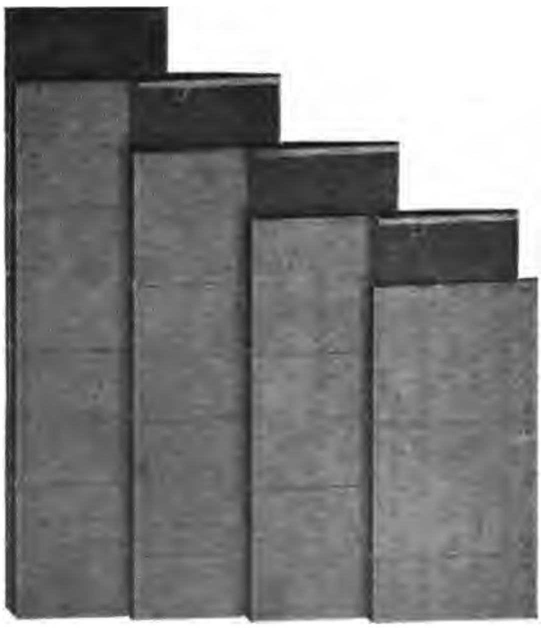


Fig. 117—Section of Shingle Tile Roof Showing Top and Bottom Tiles in Place.

The greater part of the hip rolls and crestings at the present time are made either on the drop power-press, or the various makes of hand-presses, and in most cases it will be found that plaster dies are giving the greatest satisfaction. In making hip rolls or crestings on the above

presses, it is necessary of course to have blanks of suitable size prepared by auger machines.

The blank, or blanks, if two are used as is sometimes the case, are placed in the lower die, batted down by hand, and any parts needing extra clay are supplied. The lower die is then shoved into position under the upper die, the pressure made, and the die, with its contents, is pulled out on the sliding track. All excess clay and adhering parts are cut away, a plaster saddle or form fitting the inside of the tile is placed in position, the die is turned over, or dumped, on its hinges, the hip roll coming out and resting on the plaster saddle. The form now goes to the finisher, who works it over, trims off parts that are not needed, smooths up the piece, and places it on a pallet or form to dry.

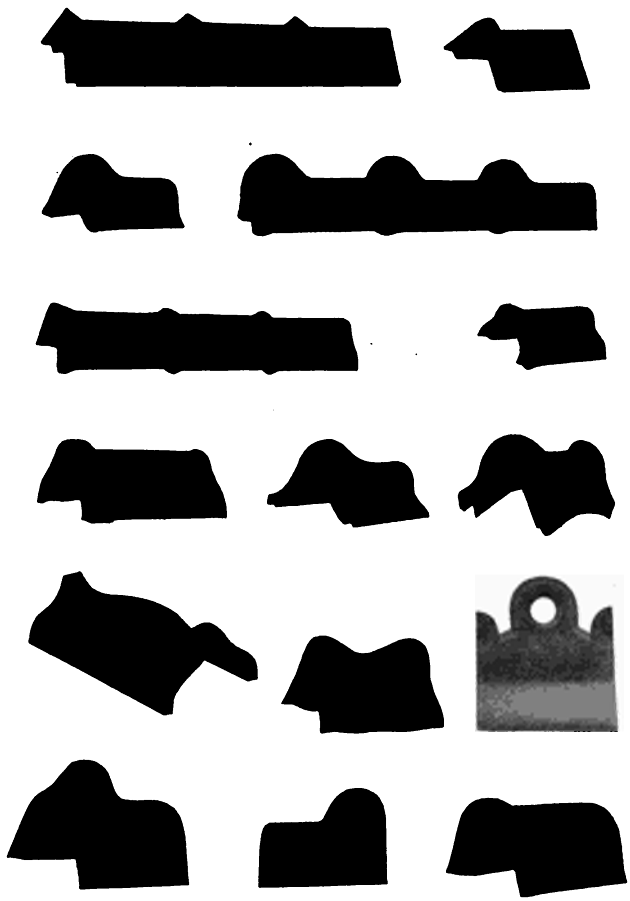


Fig. 118—Crestings.

An adjustable pitch-board upon which to dry crestings that have to be given a certain angle, as in the well known "S" cresting, is shown in Figures 121 and 122.

It will be seen that there is a base frame of two-inch by four-inch stuff. The real pitch boards are of seven-eighths-inch by twelve-inch material, the two boards being hinged together on one edge, and one of the boards being hinged to the base frame. The free edge of the other board has iron attachments to it, which engage in notches cut in the base frame, or a cast-iron notched strip attached to it. Now,

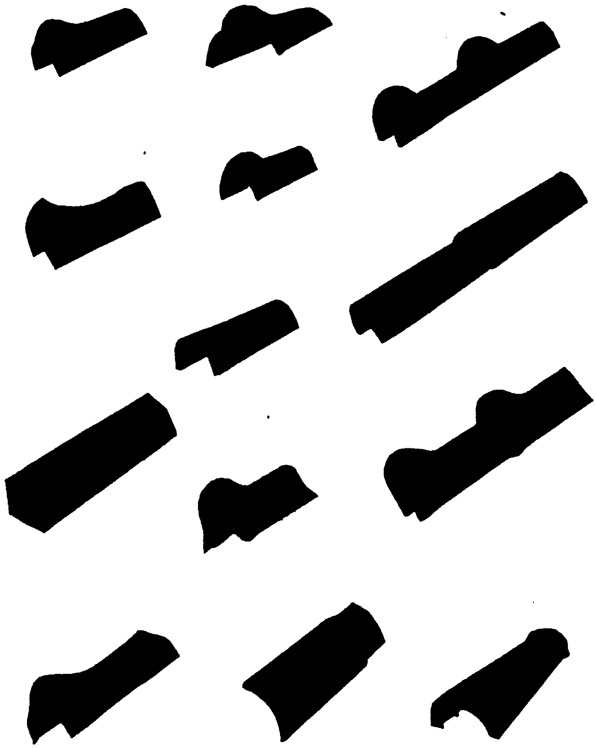


Fig. 119—Hip Rolls.

standing the boards up in an inclined position, like a letter "A," the angle can be made sharper or wider by changing the distance apart on the base plate and it only takes a moment to make the change from one angle to another. It will be noted that there are one-inch by one-inch strips nailed on the pitch boards on which the lower ends of the cresting will be supported so that it will not slide down too far and be strained out of shape. Pitch boards made in this style are convenient from the fact that when not needed they can be let down flat, and stored away in a small space.

Tapered Hip Rolls by Auger Machines.—Only one plant was found making this style of hip roll by power machinery, or, in other words, by a flow-die process. While this method is not at all new in the old world, it seems almost unknown in this country.

The Cincinnati Roofing Tile and Terra Cotta Company has for many years been making tapering hip rolls on their plunger machine by using a half-round die from which the bar issues as a semi-circular trough, having the proper thickness and with a cross-section the full size of the large end of the tile. Conical trough-shaped boxes or forms,

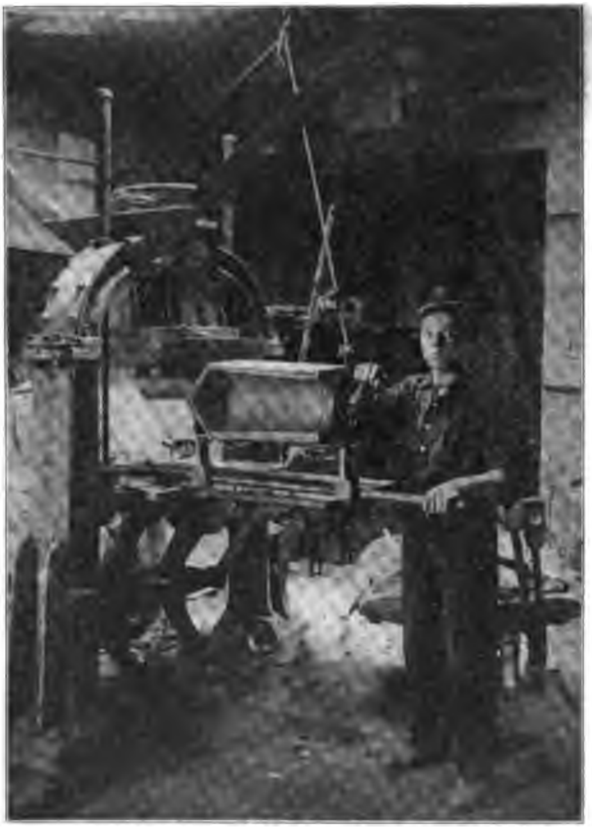


Fig. 120—Raymond Hand Press Working on Hip Rolls at Cincinnati Roofing Tile and Terra Cotta Co., Cincinnati, Ohio.

the large end of which will just admit the clay bar as it comes from the machine, are placed upon a low stand, or track, in front of the die, in such a position that they can be slid in, large end first, almost up to the die. The stream of clay being started, the operator holds one of the receiving boxes in position with one hand and guides the flow of clay with the other. The stream is compressed by the tapering mould to a cone shape. The excess clay at the small end projects up above the form. The machine is then stopped, the tile is cut off at the die, and the entire form, with the tile, is handed to the trimmer, whose duty it is to trim off the excess clay along the sides at the small end,

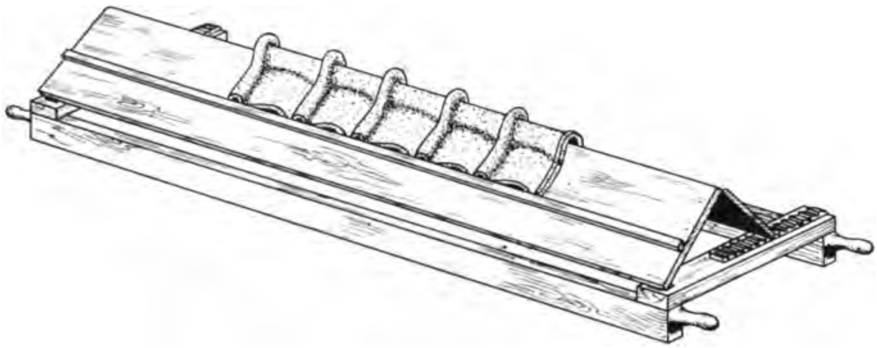


Fig. 121—Adjustable Pitch Board for Drying Crestings.

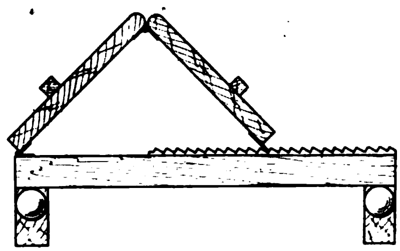


Fig. 122—Details of Pitch Board.

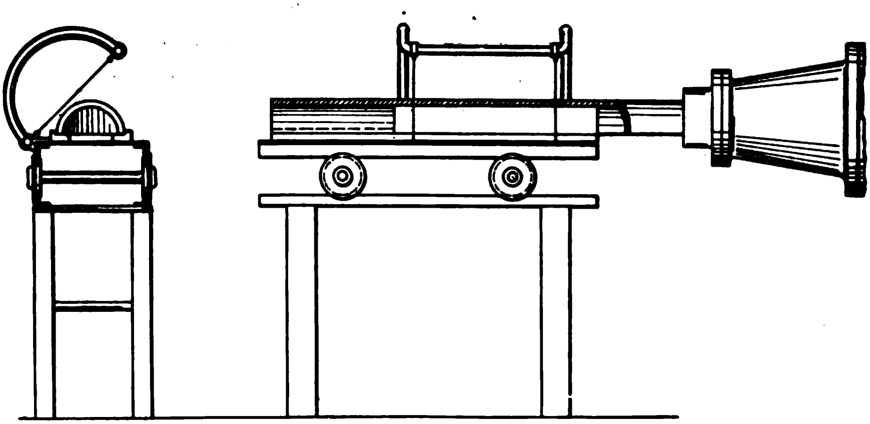


Fig. 123—Cutting Table for Handling Half-Round Tile for Hip Rolls.

cut the ends true with the form, punch the nail holes and place the piece on a pallet ready for the dryer. By having a half-dozen of the conical receiving forms, and two trimmers, it was possible to keep the machine in operation the most of the time. Three men and three boys would turn out from twelve hundred to fifteen hundred conical hip rolls per day. This method is practically only possible with a plunger machine; it would not be feasible with a continuous delivery.

With the outfit shown in Figure 123, it is believed that the output could be more than doubled by using an auger machine and the same labor force. This would make hip rolls so cheap that they could be used largely on slate roofs in the place of the metal cresting and hip covering now usually employed.

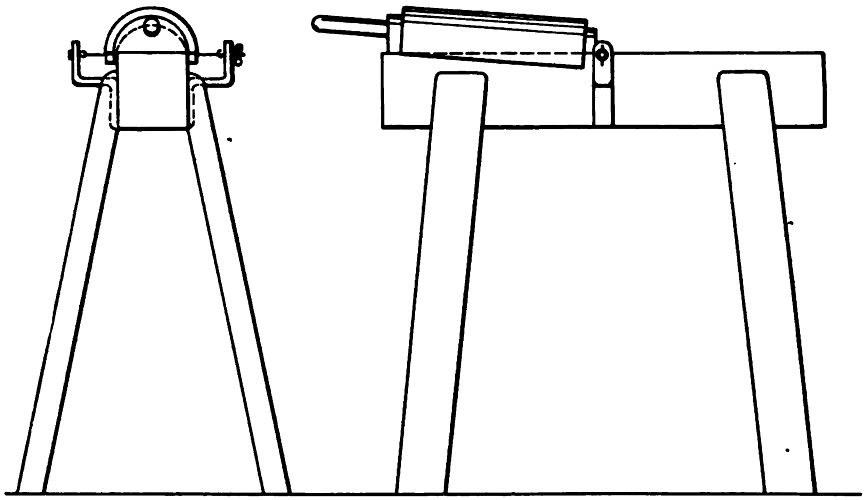


Fig. 124—Cutting Horse for Conical Hip Rolls.

The cutting frame and track may be of any design, the main feature being that the form upon which the tile travels does not extend but a short distance beyond the last cutting wire. As the tile is cut, it is pushed along by the one following. After leaving the form it is held in position by the side lugs or tracks shown in the end section. This leaves the entire tile free and clear underneath so that a paddle or form, having its outside shaped like the inside of the desired tile, can be inserted to remove it from the cutting table, and pass it on to the cutting horse for final trimming. The right angled triangles that come from the semi-cylindrical tile being made to fit down upon the conical shaped form are cut off by drawing the form and its charge over the wire on the form or horse once. Upon punching the nail holes, the hip roll is complete, ready for the dryer. By having a half dozen or more shapers or paddles, and a couple of cutting horses, the daily output could be

made to run up to two or three thousand per day without question. By using a good strong auger machine the clay could be run rather stiff to facilitate rapid handling of the tiles.

In using the ordinary drop press, or hand press, for making crestings and the larger forms of hip rolls, it will be found that the daily output of one man and a helper will run about two hundred to three hundred per day of average size, and less for the larger and more complicated patterns.

Hip Roll Starters.—The hip roll, like the regular tile, needs a "starter" or closed end tile at the lower end of the hip of the roof. More or less advantage has been taken of the opportunity to ornament the roof. An extra price is charged for fancy or ornamental hip ends, because in making them a complete regular hip roll is used, and the end is welded on extra, usually by hand in plaster molds.

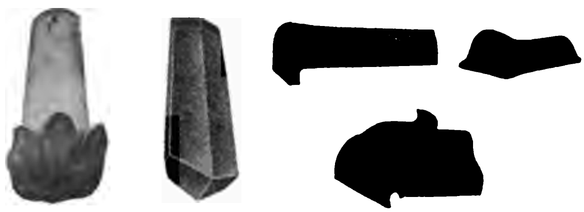


Fig. 125—Hip "Starters".

Finials.—A roof is not complete without some ornamental form of finishing piece at the junction of the ridge line with the hips, or the ridge line at the gables, or on the top of the towers.

In this class of work the roofing tile manufacturer most closely approaches to the field of the terra cotta manufacturer. Here a real chance for decoration comes into play, and the modeler can show his skill and artistic ability in the designing and making of richly ornamented pieces, ranging in size from one foot up to six or even eight feet high.

In this class of work moulds are very seldom made, because architects are so very prone to want variety. Not only will different architects not use the same ornaments, but even the same architect will hardly use his own design in a second place. Also, it is scarcely ever that two towers of the same pitch or rafter length are designed, so that the tile manufacturer has learned from experience that to make moulds of all the work turned out would be a useless tying up of money.

There are many simple finials that could be made and carried as stock finials, for the standard pitches and hip rolls, but even then, the customer is likely to want a different cresting from that used in combination with the finial, and hence it is scarcely profitable to try to carry stock. In the making of stock or ordinary finials, it will be found that each plant is equipped with a large assortment of hip saddles, or miniature roofs upon which the finials are built.

These hip saddles must be made up in many pitches to suit the varied orders that come in. It will be observed that it is made very simply, and at the same time light, for it must often be moved. This saddle is placed on a low work bench or table, with the hip end accessible. The modeler before starting sees to it that he is provided with newly pressed hip rolls and cresting of the kind desired on the completed finials; he then takes a roll of clay and builds up the hip corners with a false support for the real hip roll as shown in the following cut. He then selects two hip rolls from his supply, places them on the newly made saddles of damp clay, which have been first covered with damp paper, in the position shown in the cut. He then takes a cresting of the desired size and style, and places it in the position shown.

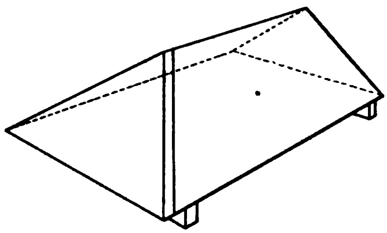


Fig. 126—A Plain Hip Saddle.

Next, he works in the "aprons" which form the connecting piece between the two hip rolls, and between the hip rolls and the cresting as shown in the cut of the completed finial (see Figure No. 128). The modeler is very careful to have the clay become firmly attached to the hip roll and cresting, so he often takes a pointed or wedge-shaped stick and works or knits the adjoining parts together.

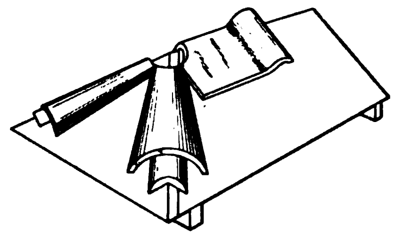


Fig. 127—First Stage of the Finial.

After the "aprons" are completed, the modeler builds up the neck for the finishing ball, which is to be added last of all. The neck is modeled onto the hip rolls and cresting in coil fashion; that is, he builds it up, a ring at a time, until of sufficient height. If a ball is to be added, it will first be hand-pressed in a two-piece plaster mould, then taken from the mould, and carefully placed on the neck previously prepared to receive it, the modeler being very careful to see that it is firmly attached.

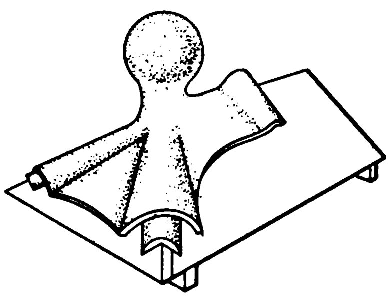


Fig. 128—Completed Finial.

The saddle carrying the finial is then set aside, and the work is allowed partially to dry before the smoothing and finishing takes place. Finally, it is carefully placed upon the cresting end and allowed to dry.

The number of finials that a good modeler will turn out will range from five to twelve per day, depending on the size and style.

Tower Finials.—In the making of round tower finials, if of the plain type, the work can be accomplished largely by a sweep revolving on a vertical axis. This was seen in use at the plant of the Celadon Terra Cotta Company, at Ottawa, Ill., a number of years ago.

A permanent table was erected about six by six feet; in the center of this table a trap door opening downward, about one foot square, was

Fig. 129—Modelers at Work at Mound City Roofing Tile Company, St. Louis, Mo.

arranged (see Figure 132). Through this trap door was a hole, through which a three-fourths inch gas pipe was run to a step in the floor and through a hole vertically above in the ceiling. This pipe represented the center axis of the finial, and served as a pivot for the sweep, or wooden shoe, which was carefully cut to the desired size and outline of the required finial.

A piece of sheet iron, forming a band around the gas pipe at the upper end of the shoe, steadied it at the top. A one-by-four-by-twelve-inch sliding strip was nailed at right angles to the main shoe to act as a guide or support at the bottom.

With the shoe in place, the modeler began to build up a central core of soft clay. This core was built out following the outline of the sweep at a distance equal to the desired thickness of the finial. This is clearly shown in the cut. After the core was complete, it was carefully covered with water-soaked newspapers. These papers were to act as a parting line between the clay of the core and the permanent exterior layer.

The work of building up the real finial began at this point, being added layer by layer, occasionally using the sweep to true up the work.

When all had been completed, the shoe was removed, the gas pipe taken out through the top, and the hole in the finial ball filled with clay. When the clay had hardened to the proper set, the trap door in the table

Fig. 130—Modelers at Work at National Roofing Tile Company. Lima, O.

was opened, and the core was dug out by hand, the newspapers acting as the division line. The hollow finial was then removed from the table, and, after turning over, was dried. For making large finials this outfit proved very satisfactory.

Graduated or Tower Tiles.—In the covering of pyramidal, conical or dome-shaped tower roofs, it becomes necessary to make special tiles to conform to the converging lines of the tower. These special tiles are known as graduated tiles; they are graduated in the sense that they start with full-sized tile at the eave line of the tower, and then become narrower, smaller and smaller with the diminishing circumference of each course, until they come to a common center at the top of the tower, or near enough so that the apron of the finial will cover them.

When an order calling for tower tiles is received, the foreman in charge of the special or terra cotta department carefully scales the plans of the tower, obtaining the length of the rafter and the diameter at the base. He then computes the circumference at the base in inches, and then divides the weather or exposed width of his full-sized tile into this circumference. If it comes out in an even number of courses around the tower, his next work is to go to the laying-out floor, which is usually

marked off in foot lines. If it comes out in uneven or fractional tiles, as is usually the case, he then makes use of what is known in the trade as a "closer" course—i. e., the extra space is either filled in with smaller

Fig. 131—Finials.

or wider tiles, as the case may require. Where smaller tiles are needed to complete the circle, it is usual to start with some other tiles in the first course than the regular full-sized tiles; i. e., one or more tiles from

the third or fourth course may be used in the first. Thus, with a little care it is possible to make the courses come out even for any tower.

Figures 135 and 136 represent a simple outfit used in laying out tower tiles, Spanish tower tiles in particular.

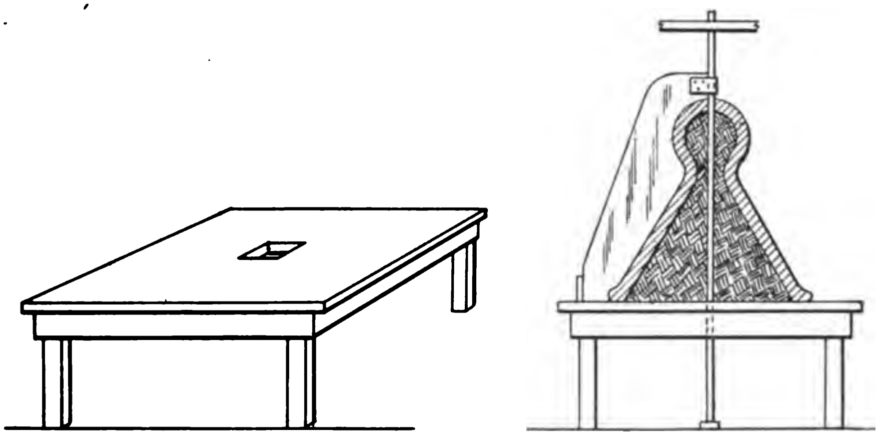


Fig. 132—Tower Finial Table.

A represents a block with two hooks attached to its top side. These hooks are spaced the exact distance apart as the width of the weather surface of a full-sized tile. The block is fastened to the floor so that the hooks are exactly even with the 0 foot line on the floor. The part B is

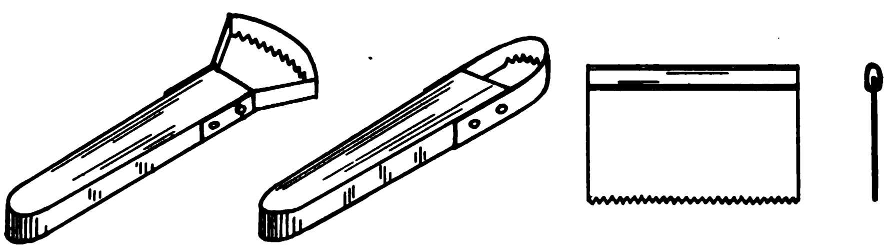


Fig. 133—Tools Commonly Used by Clay Modelers.

then fastened to the floor, on a line perpendicular to the center of a line drawn between the two hooks on Block A, and so that its hook stands at a distance equal to the length of the rafter of the tower. A line is now fastened to one hook at the base block, A, passed around the top hook and back to the second base hook, where it is fastened after drawing taut.

The rate at which the tiles diminish in width is quite different. The tiles made for a ten-foot tower cannot be used on a twenty-five foot tower, and vice versa. Hence, moulds or dies must be made for each. This is true of nearly every different sized tower. Occasionally the

tiles from fourteen-foot towers can be shifted to one of fifteen or sixteen feet. This is more easily done with Spanish tiles than with interlocking. In the interlocking tiles one has but very little play in the locks of the tiles in which the width can be swelled or diminished.

Fig. 134—Tower Covered with Graduated Spanish Tiles.

In the making of the tower tiles it will be found that the older plants are equipped with a full set of dies (plaster) for rafters of ten, twelve, fourteen feet, etc. These dies are for the most part worked on

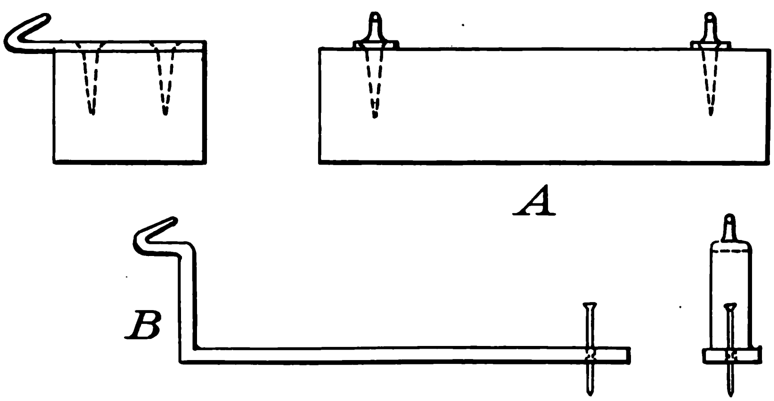


Fig. 135—Floor Hooks Used in Laying Out Tower Tiles.

hand presses. The extremely small tiles at the top are more often made by hand in plaster moulds.

On towers with twenty-five or thirty-foot rafters, where the tiles become extremely small and slender, the expedient of making double or quadruple tiles of the small ones is followed at times. Again, when two-thirds of the height of the tower has been covered, every other course will often be "jumped out;" that is, one tile takes the place of two, in order to reduce the number of slender pieces. However, this is a matter to be settled in each particular case and no law can be laid down.

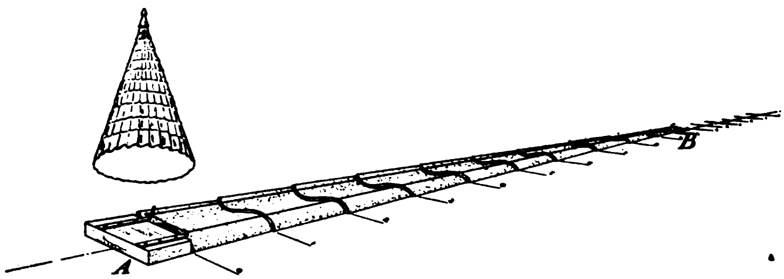


Fig. 136—Perspective View of Method of Laying Out Tower Tiles.

Rake or Gable Tiles.—It would be useless to attempt to enumerate and describe the endless variety of special tiles and shapes that the roofing tile manufacturer is called upon to produce, or sees that he must make in order to properly cover a roof.

In the regular tiles it is necessary to make rake or gable tiles in rights and lefts, to complete or close the roof at the gables of a building. In interlocking tiles, there are four different rake tiles—full right and left rake, and a half-right and half-left rake. These tiles are nothing more than the regular tiles with the side provided with a wing or lip which comes down about three inches over the facing of the gable.


Fig. 137—Spanish Tower Tiles.

Miter Tiles.—It very frequently happens that dormer window cheeks or sides are covered with tiles, and when such is the case it becomes necessary to provide a finish at the angles or corners. This is done by mitering two tiles together as one. Thus the courses of tiles run completely around the dormer and at the same time form a covering for the corners.

Mitered Hip and Valley Tiles.—With shingle tiles it is possible to make them fit in the valleys and over hips of roofs, thus doing away

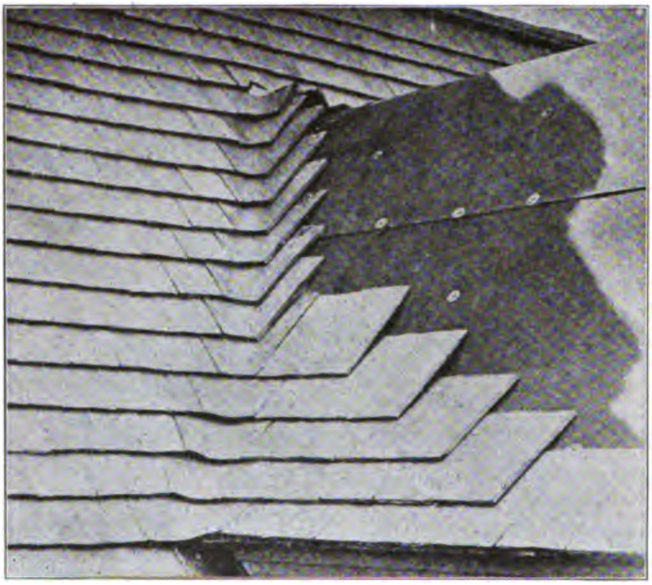


Fig. 138—Mitered Valley Tiles.

with exposed metal flashing. These mitered hip and valley tiles can be made on presses, but are most often made by hand in plaster moulds.

Ventilator Tiles.—In some instances, where there is much smoke or steam, as in foundries and workshops, it is desirable to have some means of ventilation in the roof. This situation has been met by the roofing tile manufacturers very nicely by making ventilators of the cresting tiles. The making of these ventilator tiles is hand work; that is, they are pressed by hand in plaster moulds. Very often, however, they are made by using a regular cresting, and modeling the ventilator opening and hood onto it by hand, without any mould whatever.

Deck Moulding or Coping Tiles.—In addition to the ordinary cresting, a line of deck mouldings or wall copings are commonly made. The trade in the latter is light, because wall copings are extensively furnished by sewer-pipe makers, in much heavier cross sections than the tile maker would regularly produce.

Curvilinear Tiles.—For dome-shaped roofs, or domes of towers, tiles of the regular pattern, except that they are made with a convex, outer surface, are produced. Similar curved tiles, though concave, are required for pagoda and Moorish towers. The curvature extends lengthwise of the tiles. In making these tiles, plaster moulds having the proper curvature are used. Each dome is a special problem of

itself and requires a complete set of moulds, which, as a rule, are not used for any other job.

Other Curved Tiles.—Very often in covering a curved section of roof, known as an "eyebrow," it becomes necessary to construct special tiles of extra width to allow for the increased eave line of the "eyebrow." These tiles are of the same pattern as those made on the regular machines, except that they are somewhat wider, and on the underlap side the rib is made higher to prevent the water from overflowing. These tiles are all made by hand in plaster moulds, the number required being small, and the size and curvature of the "eyebrow" to be covered hardly ever being alike.

Glass Tiles.—There is no roof so well adapted to admitting light without the use of sky-lights as the tile roof. For a number of years back, a glass tile has been made, of exactly the same pattern as the clay tile. In train sheds, shops and factories where it is desired to have overhead light, all that is necessary is to insert glass tiles, either singly or in units, along with the regular clay tiles; thus the light can be admitted at any point and in areas of any magnitude. The areas can also be changed from time to time, if necessary.

There is no other way that light can be so cheaply introduced in a roof as by the use of glass tiles, the economy being chiefly due to the fact that the first cost is the only cost. The amount of light transmitted by the corrugated surface of a tile is far greater than what could be transmitted by a plain glass pane. Another advantage is that the lines of the roof are not destroyed by unsightly sky-lights of the ordinary pattern.

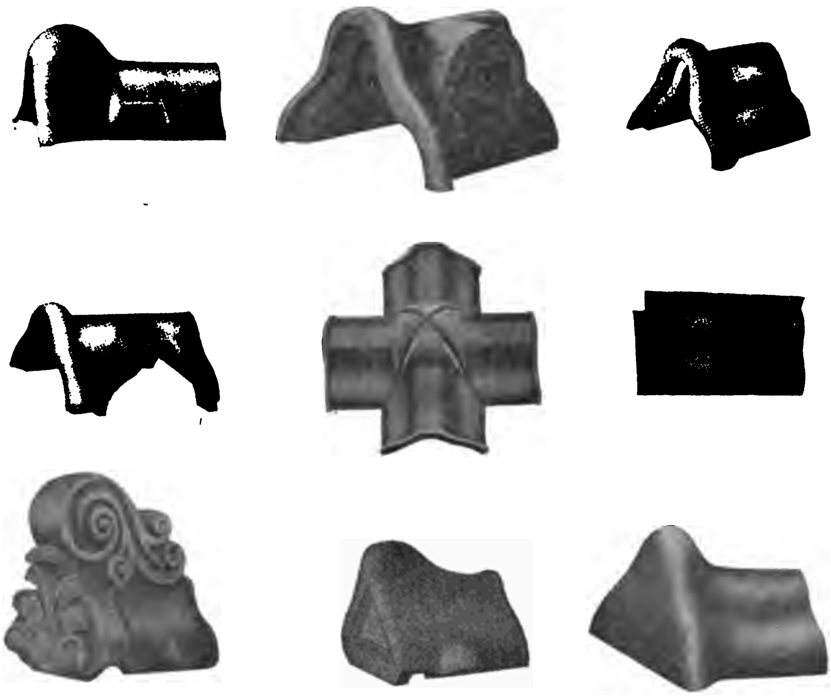


Fig. 139—Ventilator and Special Forms of Ridge Tiles.

Fig. 140—Interior. Showing Glass Tiles in Use. Furnished by the Ludowici-Celadon Company.

CHAPTER VII.

THE DRYING OF ROOFING TILES.

The drying of a soft, plastic and easily deformable clay ware is the first step in converting it into a hard and durable substance. It is a process in which much skill and knowledge of physical laws may be employed, and also one in which results are constantly gotten with little or no such knowledge. From the fact that the atmosphere is the medium by which the water of the clay is carried off in vapor form, and that this atmosphere itself will supply the necessary heat to make the vaporization of the water possible, it follows that the drying out of wet clay is certain to occur, whether desired or not, unless actively guarded against. Also, this natural drying may under some conditions exceed in economy any of the artificial processes involving use of fuel, artificial movement of air, and arrangements for controlling humidity, etc.

For these reasons a great variety of practices exist in the drying of all kinds of clay wares. The selection of the best method for any given case is not always an easy task. It involves a consideration of the following factors:

(1). The nature of the clay ware to be dried. Whether its shape, size and thickness are such as favor drying safely and rapidly, or whether it is necessarily a difficult material to get through the process without defects or loss.

(2). The peculiarities of the clay itself. Whether it has good strength, moderate shrinkage, and safe drying properties, or whether it is weak, or warps badly, cracks on the least exposure, etc.

(3). The climatic conditions of the place where the drying is to be done.

(4). The fuel supply. Of what character, whether easily obtainable and cheap, or the reverse.

(5). The quality of labor available, whether intelligent and painstaking, or ignorant and careless.

(6). The value of the product and whether its price will permit expensive work being done upon it.

In general, in tropical countries where rains are frequent and excessive, and the air humid, artificial drying is general, at least to the extent of providing covered structures for protection. In tropical or subtropical arid countries, like our Southwest, and the highlands of Mexico, the most favorable conditions for outside drying that exist anywhere

are found. In such countries, the use of any fuel is very often unnecessary. But even here the ware may require conditions not naturally afforded, and dryers heated by combustion of fuel may be necessary.

In temperate zones where dry warm weather is not likely to be persistent for long periods, and where rain and frosts are certain to be frequent for one-third to one-half of the year, outside drying can only be depended upon for crude products and at favorable seasons. Nearly all high grade clay wares require artificial drying, and the best that can be done is to be able to take advantage of natural conditions when they happen to be favorable, but to be able to dry artificially when they are not.

In the northern countries, no hopes can be cherished of drying clay wares in the open, because of the little heat, and the humidity prevailing at times of high temperature. Frost prevents such work most of the time, and artificial drying equipment is necessary.

Since all of the roofing tile industry of the United States, unless a very small output among brick plants of the Southwest be considered, lies in the north temperate zone and in countries which experience sharp winter weather, and highly humid weather in the summer, the use of artificial dryers is necessary everywhere. The nature of the ware, the difficulty and expense of rapidly moving it, the perfection required in the product, and the price obtained, all require and justify the use of dryers where heat and air supply can be controlled.

The physical principles upon which drying operations rest have been carefully studied and set forth in various works.[1] For this reason no space will be used in this connection, except for such comments as come up naturally in connection with the discussion of roofing tile dryers. The object of this chapter is to show the clay workers what kind of driers are in actual use in the roofing tile industry, and in what respects they do their work well, and in what direction changes and improvements are needed.

KINDS OF ARTIFICIAL DRYERS.

There are four types of artificial dryers:

First. The Room Dryer.—This system seeks to maintain the atmospheric conditions of a warm dry summer day, in a room or building, in which the clay wares are exposed either on the floors or on racks or shelves of some sort. The heat may be supplied in any way desired, except that it must not be from the waste gases of combustion from any source, as men must work in the dryer atmosphere with safety to health and in comfort. For the same reason, the temperatures are

[1]E. Hausbrand, Drying by Means of Air and Steam. (Translated from the German.)
R. H. Minton, Trans. Am. Cer. Soc. Vol. VI, p. 269.
D. T. Farnham, Trans. Am. Cer. Soc. Vol. XII, p. 392.

limited to 100° F., or slightly above, and usually do not exceed 85° F. This system is used almost exclusively for sewer pipe, terra cotta, glass pots, gas retorts, and all large refractory wares, and to a considerable extent for pottery of all kinds, especially the large thick-walled wares, such as sanitary goods. It has even been used for bricks of various sorts, but is not well suited to wares which must be dried rapidly and very cheaply. This type of dryer has its highest example in the sewer pipe factories, and for this reason is often called the sewer-pipe type.

Second. The Hot Floor Dryer.—This system uses a fire-proof floor, usually of masonry, but sometimes of cement, or metal, the surface of which is maintained at as high a temperature as the clays will by any possibility stand. The ware is placed directly on this floor, and is dried by the heat taken up by actual contact with the floor, and from the air currents, which the floor heats and sets in motion. This system differs from the preceding in that but one method of heating is employed, viz., the hot floor, and the ware is dried on it, and not by the maintenance of a gentle diffused heat permeating the rooms or buildings. This system originated in the fire brick business, and is almost wholly confined to that industry still. Only occasional instances of its use for any other purpose are found.

Third. The Periodic Chamber Dryer.—This system includes all dryers which use a chamber of limited size, in which high temperatures can be maintained, with rigid control of the air supply, humidity, etc. The type of this sort of dryer is the potter's hot-closet, but the periodic tunnel dryers, used for bricks, are also good illustrations of this method. It varies from the first type in the high temperatures and high humidity maintained, making the dryers untenable for men, and from the general use of artificial circulation to increase the rapidity of operation.

Fourth. The Continuous Dryer.—This system includes all dryers in which the ware to be dried is fed into the structure at frequent intervals, and taken out of another part of the structure at the same intervals. It involves the idea of progressive movement of the ware through a series of automatically varying conditions of temperature and humidity, and differs from the preceding only in this continuous and progressive character. In both, the temperature and air supply must be under close control. The same structure may, in some cases, be either as a chamber dryer, or a continuous dryer, according to its mode of operation. In general, however, the difference in operation requires considerable difference in mode of distributing heat and air supplies. The type of this method of drying is the continuous tunnel brick dryers, and the method is very largely employed for bricks of all sorts. The method is now applied to some extent to sewer pipes, drain tiles, pottery, and roofing tiles. It is the most rapid and most economical of all

methods for wares of suitable shapes and sizes and for clays which will stand the treatment, but very many clays will not stand the method at all.

ROOM DRYERS.

Nearly all roofing tile works use this method in part. Nearly all of the terra cotta pieces, such as the finials, large cresting and special shapes, modeled free-hand or pressed by hand in plaster moulds, are dried at the point where they are made. These products are not put into any special dryer, but are left in the open workroom, at least until they can be safely handled, when, in some few plants, they are moved into smaller, hotter rooms, and placed upon racks or slatted drying floors, under which are placed steam pipes. These auxiliary rooms are usually about ten by ten feet, and have a single deck only, and are used only to complete the drying of the ware after it has gotten beyond the shrinkage period, and to make it ready to go to the kiln.

This system of drying is the typical one for this part of the product. In some of the later plants, where tunnel dryers are used, the terra cotta room is built over the cool end of the dryer. As the ware is made it is set along the floor (the roof of the tunnels made level) at a point where the temperature is best suited to the style or size of the piece in question. By this system it is possible to dry a considerable amount of ware without extra cost, there being sufficient radiated heat escaping from the tunnel at all times to do the drying of the shapes and terra cotta. There is a little inconvenience arising under this plan, from the fact that the clay for modeling the terra cotta must be elevated to get it to the terra cotta room on the dryer, and the finished ware must be brought down to the ground floor for loading in the kilns. The excellent drying space afforded and the waste heat here available more than offset the cost of elevating and lowering the clay and ware, which can be done very cheaply by conveyors or elevators.

Another advantageous feature of the dryer above the tunnel is that the plant can be kept more compact and better arranged. The clay comes to the end of the dryer nearest the pugging machinery, and when manufactured and dried passes down at the end nearest the kilns, where it is needed. In some plants the terra cotta work is made in a room at right angles to the main machinery room, and when the ware is dry it has to pass out around the drier and be carried its full length before reaching the kiln yard.

In the illustrations showing an outline plan of the United States Roofing Tile Company's dryer, the use made of their dryer top for a terra cotta molding and drying room can be seen. The same method was also found in use at the plant of the Western Roofing Tile Company, Coffeyville, Kansas.

PERIODIC OR CHAMBER DRYERS.

The preceding dryers have in both cases been used for the drying of the special tiles and roofing terra cotta, but not for the regular tiles which compose the bulk of the output of the plant. For the latter purposes the room dryer would be scarcely applicable, because of the slow drying which it is specially designed to give. Slow drying is necessarily correlated with small output. However, there were found two dryers for roofing tiles, which are almost as closely related to the room dryer as to the chamber dryer under which they are here classified.

The Bennett Dryer.—This dryer was employed by the Bennett Roofing Tile Company, Baltimore, Md. It was the simplest dryer found in use. It consisted of permanent shelves, or racks, in a closed room. The tiles were pressed on a small pentagon press, caught on wooden pallets, then pallets and tiles were placed on a continuous belt elevator, which took them to the second floor, where they were removed by boys or men who took them to the shelves of the drying room. The rooms were about twelve by twenty feet, divided into narrow walkways between permanent built-in racks, having slatted shelving. The racks were about four feet wide, so that tiles were put in and taken out from both sides. The heat was supplied by steam pipes laid under the racks a couple of inches above the floor. The racks being slatted, the ascending currents of heated air were able to pass among the tiles more or less freely.

This dryer was very similar to the finial or terra cotta dryers previously described. It differed in the quantity of ware crowded into a small space and in the fact that the dryer was loaded, closed, heated by piping until the contents were dry, and then emptied. The room dryer always had ware in all stages at the same time, and its conditions permitted all parts of the process to go on safely together. The Bennett dryer dried a charge at a time, and had to be cooled down for drawing and recharging, and therefore is a periodic or chamber dryer. The Bennett dryer was defective in that no particular provision was made for ventilation other than the natural leakage of any rough boarded room. The air in the dryer undoubtedly soon became fully saturated with moisture, and then drying would only take place as new and dry air leaked in to take the place of the water-laden atmosphere inside. By using ventilator stacks or a fan, it would have been possible to have gotten much more work out of this amount of dryer space. The cost of loading and unloading this dryer was much too great.

It should be understood, however, that in this particular case, the plant was not really run as a strictly business proposition. It was maintained largely as a hobby by its owner, Mr. Bennett, whose major time was taken up by the cares of a large and successful white-ware pottery.

The Cincinnati Dryer.—The dryer used by the Cincinnati Roofing Tile and Terra Cotta Company consisted of rooms fourteen by forty feet by about eight feet high. Figure No. 141 shows a side view and cross-section of one room. Along each side, and parallel with the floor, are spiked two by four inch cleats at intervals of about eight inches. These cleats extend the full length of the room on each side, and act as the supports for the movable shelves that are put in as the filling of the dryer progresses. The shelving is pine composed of plain seven-eighths inch by ten-inch boards.

It will be noticed that though the dryer room is ceiled, it has three ventilators which extend up above the real roof of the building. At the back of the dryer, at the left-hand end, is a six-inch steam pipe or "header," out of which, at intervals of eleven inches, one-inch pipes are taken. These pass along the floor of the dryer to the other end, where they empty into a smaller header, which drains into a steam trap. The floor of the dryer is perforated with auger holes, to admit air under the pipes.

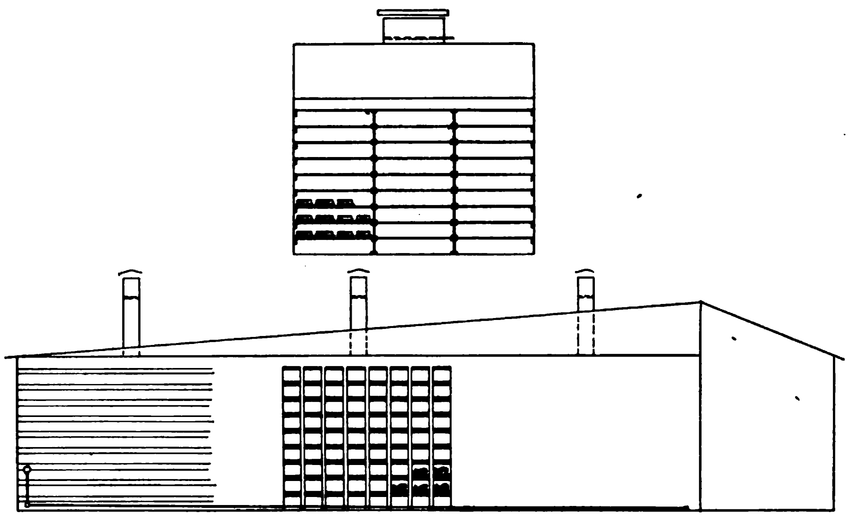


Fig. 141—Dryer Used by the Cincinnati Roofing Tile and Terra Cotta Co. Cincinnati, O.

The operation of this dryer is strictly periodic. The tiles are placed three-deep on a pallet. The pallets in turn are placed on a two-wheeled "buggy" (Figure No. 101), and run down the hallway to the room that is to be filled. A runway for the buggy extends the entire length of the dryer room. The first stand or tier of portable shelving being in place, the pallets with their tiles are unloaded upon them as shown in the end views of dryer (Figure No. 141). When the entire first stand is filled, a new one is started by putting in boards, three inches in advance of the front of the stand just filled (see side view in Figure No.

141). In order to keep the shelves from sagging down in the center, portable uprights are inserted between shelves, one above the other, as shown in the end view of the dryer. These uprights are eight inches by ten inches, with one-inch cleats nailed on both sides at each end to give it stability. Stand after stand is erected and filled until the entire length of the room is occupied. It takes from two to four days to fill a room. It is then closed by sliding doors, steam is turned into the pipes, the dampers in the ventilators are partly opened, and the drying proceeds, using live steam at night and exhaust from the engine in the daytime. The drying out of a room full of tiles takes from six to fifteen days, depending on the conditions. After the tiles are dry, they are often allowed to remain in the dryers as storage rooms until needed for setting. The rooms each hold in the neighborhood of fifteen thousand tiles. In drawing, the door is opened, a temporary bench set up, and the tiles from the outside stand are taken down, beginning at the top, pallet by pallet. Each tile is then carefully looked over, and if true and perfect is placed on a pile from six to twelve deep on a pallet, set on a buggy and trucked to the kiln.

This dryer is certainly a very crude and cumbersome affair. So far as can be seen, it has no advantages over other forms, and it certainly has disadvantages. For drying a very tender clay, its action is slow and gentle and would probably avoid much cracking, but there are better types for this purpose.

Its greatest disadvantage is in the great cost of time and labor in filling and emptying. It is necessary to put up and take down the entire shelf-and-stand equipment. If an auger machine were used to make the tiles, one man could not put up the stands fast enough to take care of the output, but the plunger machine used in this plant is of small capacity and the dryer has been evolved to work under these conditions. The construction is all cheap wood work and hence perishable by fire or rot.* The rate of drying is exceedingly slow, very frequently taking twelve to fifteen days to get tiles ready for the kiln. The heating surface of the pipes is entirely too small for the amount of work to be done, and the circulation of the air through the densely packed room is too sluggish. An exhaust fan system to increase the ventilation would be a marked improvement, either with or without increased heating capacity.

This type of dryer is not practical for any but small plants. A dryer after the Bennett plan, having fixed shelves, would prove more economical to operate in the large way, and owing to the opener arrangement would be more rapid, provided proper facilities were made to heat and ventilate the rooms.

*Since this was written, it has been destroyed by fire.—[Ed.]

The Huntington Dryer.—A periodic dryer of somewhat higher type in construction and operation was found at the Huntington Roofing Tile Company. The tiles are here placed on steel pallets, which are loaded on rack cars, which are then run into the drying room. They pass through the dryer in from twelve to twenty hours, and are then unloaded, repiled on wooden pallets, and allowed to stand in racks in an open shed until air dry. This system is quite unusual. The dryer proper was designed by the Barron Dryer Company, of Chicago, Ill. It consists of a low rectangular room, high enough to hold the rack dryer cars; and filled with parallel tracks. Steam coils are placed under the car tracks at the outlet end of the dryer, extending back three or four car-lengths, or about twenty-five feet. The heat is furnished by exhaust steam in the day time, and live steam at night. At the inlet end of the dryer is a large stack, which extends up twenty or more feet. The cars of tiles on entering pass directly under the stack, and thus come in contact with the escaping moisture-laden air from the cars farther down in the dryer. The cool green tiles often condense moisture on their surface before commencing to dry. The tiles receive the greatest amount of heat on reaching the zone over the steam coils. The dryer is provided with doors

Fig. 142—Buggy of Dry Tiles on Way to the Kiln.

at each end, and the ventilating stack is controlled by a damper, so that the flow of air through the dryer can be regulated. The dryer thus far described is about the ordinary tunnel dryer with the partitions left out. But as used at Huntington, it is different from the usual operation of a tunnel dryer. The time that the tiles are in the dryer varies from ten to twenty-four hours. The tiles still show marked signs of color on the surface, from the remaining moisture, and are in the so-called "leather-hard" condition. The cars are then run out on to a transfer car, moved over to open rack sheds, and the tiles are transferred from the metal pallets which are one-eighth inch thick by about sixteen inches long. The tiles lie on these in single thickness

only, but are now stacked from twelve to twenty deep on other pallets in the shed, where they remain sometimes many days, so at least until the tiles are air dry. The sheds therefore serve not merely as dryers, but also as storage for tiles ready for the kilns. For setting, they are loaded, still on their pallets, on to trucks and taken to the kiln.

The advantages claimed by the company for this method are several: *First*, a much smaller number of cars and iron pallets are needed, which materially reduces their investment. *Secondly*, owing to the small kiln capacity, they would be obliged to run the plant frequently for short periods, whenever they had a kiln empty, but by their ample shed storage they can run the present plant continuously for a time, until everything is full, and then shut down for a considerable time, until the sheds are nearly depleted. They consider this more economical than the other plan.

There are, however, some stronger reasons why this method is locally a success. As stated elsewhere, this company has been running exclusively on flat shingles, and without doubt is turning out a greater per cent. of number-one goods than any other concern on this style of tiles.

In studying the conditions under which they work, we must turn back to their raw material. They work two shales, one a fat plastic body which lends strength and good color; the other is a very sandy shale, which is used to control the shrinkage. The blending of these two shales is carefully watched. The grinding and screening is to one-sixteenth inch mesh. The clay is pugged rather softer than usual, as they have only small machines for making the shingles and cannot work the clay very stiff without breakdowns. The tiles come from the auger so soft that the pallets must be perfectly straight, or the tiles will be warped by the pallet. This soft condition of the clay permits the grains of hard shale to find water so that they slake or soften before the drying takes place. This permits the internal strains to adjust themselves. The drying proceeds slowly; only enough of the water is evaporated in the dryer proper to bring the tiles to a condition where they can be handled without marking. Thus very few if any drying strains have been developed in the tiles, and if there are any such, upon being placed in the open sheds, the extremely slow drying in piles allows them to readjust themselves. So that, when the tiles go to the kiln, they are in the best possible condition.

This method of drying as a whole, while producing very good results in this plant, can not be recommended for general application. The cost of the extra handling is considerable, and we have no evidence that the clay mixture would not produce equally good straight tiles in as high proportion by rapid drying in an efficient dryer as by this plan. We can only say that good results are secured by the present cumbersome and expensive process, made necessary by the lack of correlation of the

making and burning departments. Another bad feature of the system is that it can only be operated during the warm months. This, however, could be easily improved or overcome by having the sides closed by doors or canvas curtains, and with a few lines of steam pipe, or a little waste heat from the kilns, the sheds could be kept at a temperature well above freezing during the winter months. There are some objections also to the dryer itself. The steam pipes under the floor are extremely hard to get at in order to make repairs. The draft or the circulation of air through the dryer is created entirely by the stack. Under favorable atmospheric conditions, the ventilation will be sufficient, but on warm damp days the draft will become very sluggish, and the drying in consequence will almost, if not entirely, cease.

Another bad feature is that the interior space is one large open room, in which the natural flow of the hot air will be along the lines of least resistance. This most frequently is along the ceiling, and at times it crosses the dryer at various angles to the point in the vent stack having the best draft. If the space were divided into single or double track tunnels, the air currents would be much more under control.

The Cloverport Dryer.—A similar dryer is in use at the Murray Roofing Tile Company. The tiles at this plant are made in the same manner as at Huntington. They are loaded on iron rack cars, and run into an eight track single room dryer about seventy feet long. The heat for this dryer is supplied from two sources: first, steam pipes placed on the floor, and second, a fan and steam-coil system, furnished by the Green Fuel Economizer Company, Matteawan, N. Y. The use of the fan tends to produce a better circulation, but the dryer is largely open to the same objections as the Huntington dryer. There is no direct control of the movement of air through the room. The use of both steam pipes on the floor and a hot air fan system is unusual, and at first sight, might seem unnecessary. But the presence of the hot pipes all over the floor insures circulation by convection currents, and while the fan may be sending volumes of warm air into the dryer, it may be following lines of least resistance around or across the tops of the cars, and thus without the aid of the pipes a poor result might be attained. The open room is chiefly responsible for this, and if the space were cut up into tunnels, the double heating system would be less likely to be of use.

Fig. 143—Steam Coils.

One thing may be said of the large open room, viz., the mass of ware contained at once is great, and the proportion of walls and dead work to heat up and cool down with each charge is much reduced. The

ware is slower to dry in such a mass and is safer from cracking on that account. It is a method which might be considered with a tender clay, where it would be rejected for a strong, safe drying clay.

CONTINUOUS DRYERS.

Tunnels Heated by Steam.—This style of dryer is used in five of the roofing tile plants, a larger proportion than any other type. It is possible that this large use is not due to any special superiority over other styles, but to the fact that it can be very easily adapted to plants of various sizes, and with less initial expense than the waste heat system. Continuous dryers are usually built in the form of single track tunnels, from eighty to one hundred and twenty feet long, and from three feet six inches to four feet six inches in width, to suit the cars. The matter of single or double tracks is not of much importance as far as the drying is concerned. There is less wall to keep hot in the double track tunnels. The real advantage of the double track tunnel is that it is easier cleaned and more accessible in case of a breakdown, or some other trouble with any of the cars. In cost of construction, it is a little cheaper to build the roofs of single tunnels than with double, when either brick arches or reinforced concrete is used as the cover. If brick arches are used, the rise of the arch gives a waste space above the tops of the cars, and the hot air, unless prevented by stoppings fitted in at intervals, will tend to pass along over the top without coming into much contact with the ware. Flat roof construction, either of book tiles, or blocks, or cement concrete, are all perfectly feasible, and free from the above disadvantage.

The length of the tunnels should depend on the particular clay to be dried; shorter for the easy quick drying clays, and longer for those more plastic and difficult to dry. It is very rarely that the dryer need be over one hundred and ten feet long, exclusive of the loading and unloading tracks at either end. These tracks as usually built are of two car lengths at the receiving end, and three or four at the unloading or cooling end.

The outside walls are usually nine or thirteen inches thick and the inside or partition walls are four inches for single track and nine inches for the double track tunnels. The arch of the roof, if of brick, is usually from four to eight inches thick, and is coated with cement if to be exposed to the weather. If used as the floor of the terra cotta drying room, it is either made level with sand or cinders and then cemented, or a slatted board floor is laid over it.

The heat necessary for these dryers is supplied by either live or exhaust steam, or both at the same time. The heating system consists of a series of independent steam coil units arranged along a header in a compact group. These coils are contained in a metal hood or case,

and the air is blown or sucked through the coils, coming into intimate contact with them. These heating coils are so close spaced, and the frictional resistance they offer to the passage of air is so great, that they

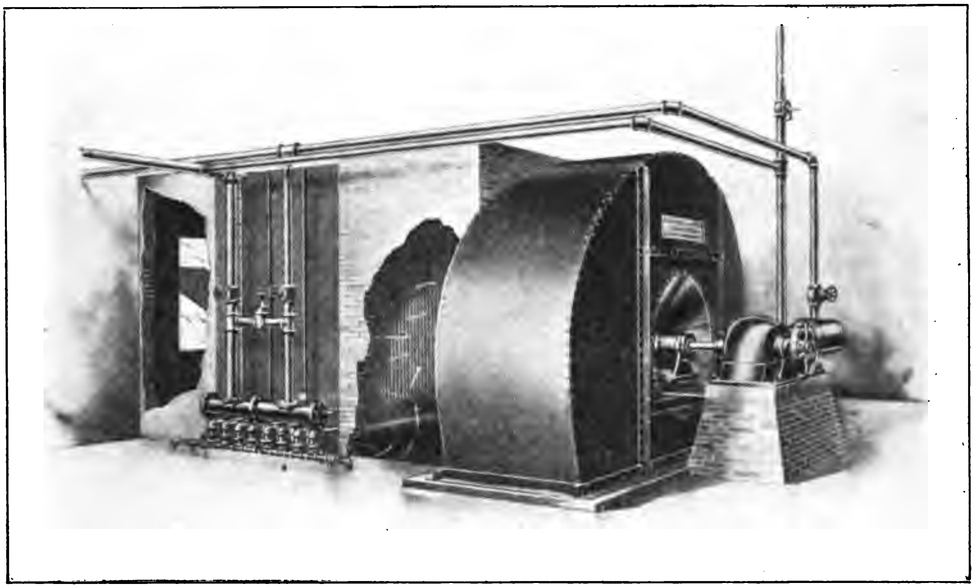


Fig. 144—Fan for Dryer.

cannot be operated without power draft in some form. Fans are generally used to pull the air in among and through the coils. The air takes up heat rapidly as it passes through, and is often too hot and is diluted with cold air at the fan so that a mixed and tempered air current of greater volume is obtained. The air is delivered to the tunnels through underground flues usually, which connect into the lower end of the dryer near the door.

In some dryers of this type the hot air is all liberated at a single opening in each tunnel; in others it is liberated through smaller holes, at intervals of each two feet or so, back to a distance of twenty to thirty feet from the outlet end. The distance that these hot air vents in the floor can be carried back up the tunnel will depend very largely upon the drying quality of the clay. The safer the clay, the farther toward the incoming end can the hot air be carried. Tender clays do best when only one opening is made at the lower end.

The fact that the steam coils are in independent sections admits of easy adjustment as to the quality of heat furnished. The source is also under control, as either exhaust steam or steam direct from the boiler, or both, can be used at the same time by admitting them into separate sections of coils. This feature, in connection with regulation of the speed

of the fan, gives the operator almost perfect control of the drying conditions. It is common at the upper end of the dryer, where the moisture-laden air is discharged, to have a small auxiliary fan to assist in moving the wet air out of the dryer. In some cases ventilators are used, but these are not so satisfactory as the small fans. There seems to be no first choice as to the selection of fans. The following firms have each installed one system in a roofing tile plant: The American Blower Company, Detroit, Mich.; The New York Blower Company, Bucyrus, Ohio; The Green Fuel Economizer Company, Matteawan, N. Y.; The Buffalo Forge Company, Buffalo, N. Y.; The Garden City Fan Company and The Sturtevant Company, Boston, Mass.

The Parkersburg Dryer.—The equipment for this dryer was furnished by the New York Blower Company. The above sketch was taken largely from their drawings. The terra cotta room above the tunnels was added by the owners.

It will be seen that this dryer is of the single track type, the tunnels being forty-four inches wide, six feet high and eighty feet long. The large exhaust flue at the upper end is fifty-four inches by fifty-four inches, and is provided with a low stack at one end for ventilation. In most cases it would be better to have an exhaust fan at the stack end, but in this particular case the tunnels are comparatively short, and the fan is only lightly loaded, so no trouble is experienced from sluggishness on the part of the dryer.

The hot air ducts under the floor of each tunnel are eighteen inches by twenty-four inches at the intake, and taper up to about six inches by eighteen inches at the inner end, which is about twenty-five feet from the main flue. The latter, leading from the fan to the dryer, is forty-one inches by forty-one and one-half inches, the bottom rising gradually until it is only about twenty-four inches deep at the tunnel furthest from the fan.

The fan is a regular ten-foot three-quarter housing, bottom discharge steel fan, the wheel of which is six feet in diameter by three and one-half feet face. The power necessary to operate the fan is furnished by a small twelve horse power horizontal slide-valve engine, made by the company that made the fan.

The heater for this outfit consists of eight independent sections of steam coil. During the daytime exhaust steam from the engine operating the plant is used, being brought to the dryer through a five-inch asbestos-covered line. The exhaust from the small fan engine is also turned into the heater, so that very little loss of steam takes place. At night the heater is supplied by a three and one-half inch live steam line direct from the boiler. The usual time of drying in this dryer is twelve hours, although ten hours have been found sufficient.

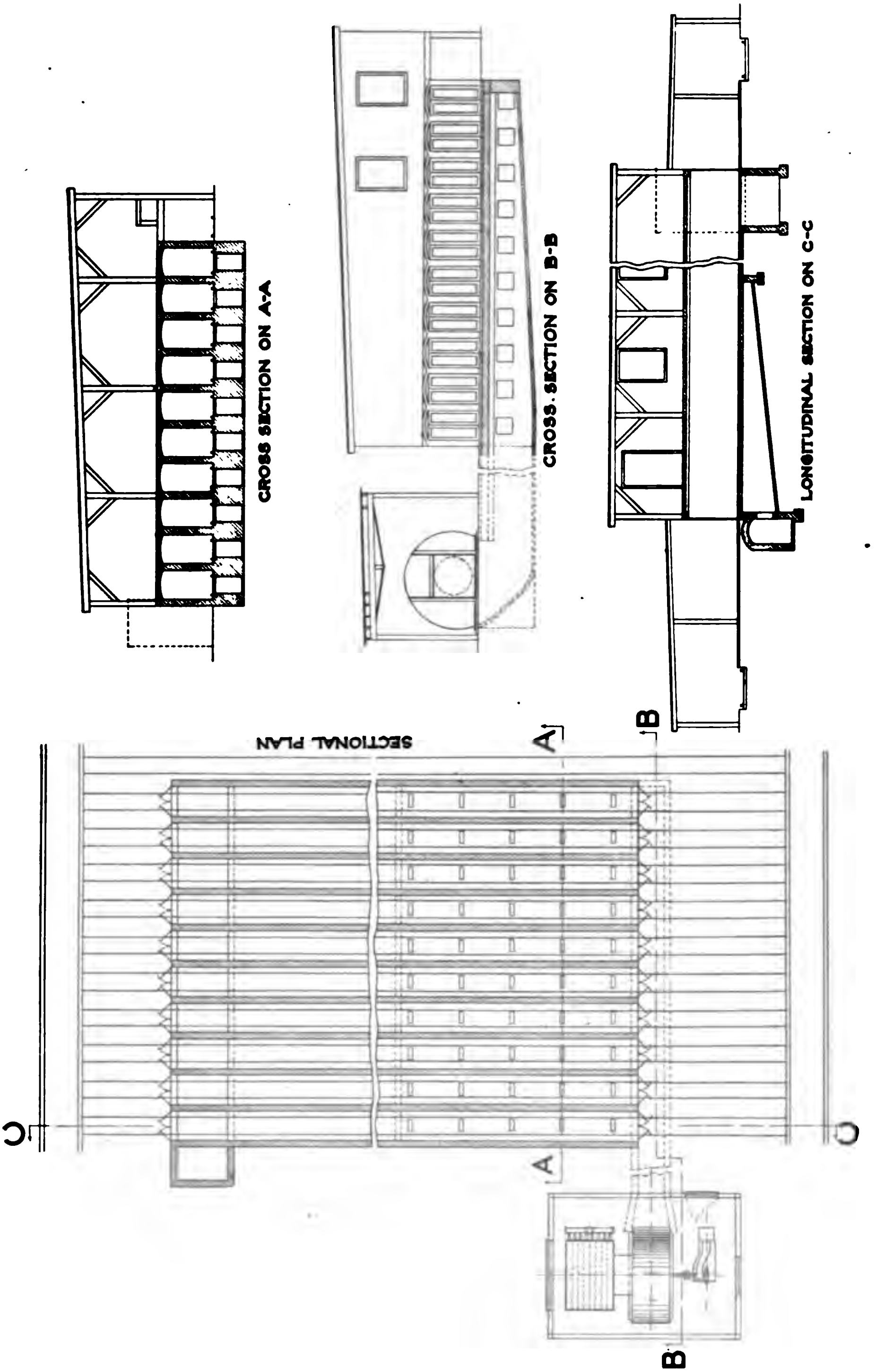


Fig. 145—Plan of Dryer at United States Roofing Tile Company, Parkersburg, W. Va.

While there are roofing tile plants with dryers of much larger size than the above, they are the same in principle. About the only objection to this type of dryer is that during about one-half of the time it is necessary to furnish live steam to the coils. The engine of the plant is not in operation more than ten hours, so that a boiler must be kept in commission for no other purpose than to furnish steam to the coils and fan engine.

There are many points in favor of this type of dryer:

First. It is suited to roofing tile plants of moderate size, where there are not sufficient kilns being burned to give a steady supply of waste heat.

Second. Its supply of heat is under perfect control—by opening or closing steam valves it can be increased or decreased at will.

Third. The rapidity of the process is favorable to the avoidance of scum.

Fourth. The economy of the dryer, if worked to its capacity, is very great. If worked to only a half or a quarter of its capacity, however, the loss of heat by unsaturated gases escaping is very high.

Fifth. The dryer is substantially independent of outside weather conditions, either for temperature or draft.

Sixth. The system is elastic—by building more tunnels, adding a few more coils of heating pipe and speeding up the fan, a considerable increase in output can be secured at small cost if the original installation was at all generously designed.

After the dryer is once filled, and the work is properly started, it will be found that the cars entering the dryer pass at once into a warm, moist atmosphere, where the tiles warm up without starting to dry. After a car or two has been pulled out at the lower end, and the car of green tiles is moved down into the dryer a couple of lengths, the drying commences, and from time to time as it moves forward, it encounters constantly hotter, dryer air, until it passes out at the lower end, with the tiles perfectly dry and hot, ready for the kiln.

The tunnel dryer using steam is and will be the one most largely used in roofing tile plants. It cannot be claimed as the best in economy of fuel, but its convenience and freedom from dependence on the kilns for heat make it more popular. The fuel cost of drying is not a serious item in the roofing tile business anyway, and convenience is very apt to outrank it, with most manufacturers.

Tunnels Heated by Furnaces.—This form of dryer, originally brought out as a patent by Sharer, and at one time extensively used, has given place largely in later years to others which derive their heat, in part at least, from the waste heat of engine rooms or kilns. Only one plant, that of the National Roofing Tile Company, Lima, Ohio, was found using a furnace-heated dryer. This dryer contains thirty single track tunnels, sixty-seven feet long, and about three feet wide

and six feet high, each. The method of applying the heat differs from the usual Sharer dryer type, in that the flues under the floor are at right angles to the tunnels, instead of coinciding with their lengthwise axis, as usual. The furnaces are built on both sides of the dryer, alternating with each other; i. e., the furnaces on the right-hand side deliver into flues, which pass under the floor to chimneys at the left-hand side, and *vice versa.* Thus a furnace and a chimney alternate along both side-walls. The idea of having the furnaces alternate in direction was to equalize the temperature from side to side of the dryer.

The furnaces are of the common flat-grate type; the dimensions of each are about eighteen by thirty-six inches. When this dryer was first installed, it was gas-fired, but as gas became more expensive, resort was had to coal. The air for ventilation is let in on the floor level at the outlet end. The escape is through numerous vent pipes or stacks in the roof.

In firing the dryer under normal conditions, the furnaces nearest the outlet end are fired much harder, or at shorter intervals, than those at the inlet end, in order to adjust the temperature to the continuous dryer principle, and not have the green tile entering at once with an extremely hot, dry atmosphere. The use of small individual stacks all over the roof instead of the single delivery at the inlet end is contrary to the continuous principle, and resembles the typical periodic dryers for bricks. The dryer is therefore not true to either type, but in operation most nearly resembles the continuous type.

The advantages of this method of heating a dryer are few, if any, for the roofing tile industry, while the disadvantages are very apparent. In the first place, the cost of operation is very high. The consumption of fuel takes place under very wasteful conditions, and at the same time requires the attention of one man, day and night. The proportion of the heat generated which finds its way up through the fire-brick floor and performs any useful work in passing vertically upwards from the floor to the roof and out, is very small indeed—probably not ten per cent. The largest part of the heat passes out of the stacks at the ends of the flues, without ever entering the dryer at all, and what does enter the dryer is not brought into contact with the ware for a long enough time.

The control of the temperature is not at all close. The tunnels along the sides and over the furnaces receive much more heat than the central ones. There is no means of regulating this difference.

The provision for admitting and controlling the air in this dryer is also poor. The low vent-stacks furnish but a slow circulation, and as the air is admitted on the floor, and not under it, and all at one end, the opposite end is nearly devoid of draft, which causes the deposition of dew on the tiles, and tends to bring out whitewash from the soluble salts in the clay.

There is still another feature not to be overlooked, viz., the flues are very apt to become choked or clogged up with soot, when the firing is done with coal. Even though they may not become so choked as to stop operations, they will become coated with layers of soot, which is an excellent non-conductor. Radiation through this soot layer is very slow, and the greater part of the heat passes up the chimney into the air.

In any case, it certainly is poor economy to consume fuel for drying purposes when there is daily much more heat wasted around the kilns and exhaust steam from the engine than would be needed to do all such work.

Tunnels, Using Waste Heat from Kilns.—It is the usual plan in this country, after a kiln of clay wares has been burned off, to allow heat contained in the ware and kiln itself to escape or radiate into the air, without any attempt being made to utilize it. Hence the term "waste heat" has been applied to heat obtained from this source.

While the use of waste heat for drying is the most economical in the sense that no new fuel is consumed to dry the ware, and should be everywhere used if possible, it is only recently used in America in any important way, and up to the present the roofing tile makers have been slow to adopt it. The limited use of this method can be explained. Many of the roofing tile plants are only of moderate size, having from two to four kilns; hence the supply of waste heat is not continuous, and other provision would have to be made to furnish heat, when there were no cooling kilns available. This is accomplished in some of the plants that are using waste heat, by having steam coils in connection with the waste heat system. At most clay plants, an auxiliary furnace, often of large size and considerable cost, is used to supply heat in connection with the fan system, when no hot kilns are available. The auxiliary furnaces, if constructed to heat the air indirectly, by radiation, are satisfactory as to quality of hot air produced, but are costly. If constructed so as to utilize the waste products of combustion, or direct heat, they are economical in fuel consumption, but scum the ware by sulphur fumes if there is the least chance. Hence, for wares which are sold on their looks, the direct heater is justly feared. The necessity of constantly having to shift from waste heat to other heat and back again has no doubt held back the use of this system as much as any other one condition.

The first cost is considerably over that of the steam system, and this has probably held some plants back in adopting the waste heat system. However, this reason should not stand in the way, for in the end any other system will exceed the waste heat system in cost of operation and maintenance.

The equipment for a waste-heat dryer, as usually constructed, consists of either single or double track tunnels built on the same plans as

for steam drying. The underground flues in the tunnels and those from the dryer to the fan remain the same. The fan and engine will differ very little. They may be furnished a little larger, and it is advisable to have the main shaft bearing of the fan water-cooled. A trunk flue, or tunnel, leading from the fan house to the kiln yard, with side branches reaching out to each kiln, must be constructed. This system of flues can either be underground or overhead, the former being the general practice. Only one plant was found using the overhead system. By referring to the illustration of the Western Roofing Tile Company (Figure 183), the large overhead flues, or ducts, can be seen leading from the kilns to the fan house. The heated air may be taken from underneath the kiln by a cross-flue. This method is the best, because the air coming in at the top of the kiln or over the bags has to pass down through all of the ware before reaching the flue, thus accomplishing the most work. However, one drawback to this method has been experienced, viz., to find a damper that will hold tight, so that when the kiln is burning the gases of combustion will not be sucked through into the waste heat flues by the fan. These gases of combustion are quite likely to form whitewash or scum on the green tiles in the dryer. Also danger arises from their escaping into the factory workroom, thus making the air unhealthful for the men.

There is no serious mechanical difficulty about making air-tight hot-air valves to stand temperatures exceeding 800 degrees centigrade. but it cannot be done with simple iron castings, for they will warp, crack, oxidize and get leaky. The best method is to use well-made, true fire-clay slabs, covering a hole in the flue bottom. If iron is used it is best to depend on a hemispherical bell to cover the opening in the flue, and let this bell seat itself in an annular cast-iron ring filled with fine sand. If, when the valve is open, the bell is pulled up out of the path of the gases, it will not warp or crack, and can be used for a long time. The sand joint is tight enough for such work as is here under discussion.

Another method of drawing the heat out from a cooling kiln is through the wicket (door) by a portable gooseneck. Instead of having the waste heat flue lead back under the kiln bottom, it is carried to a point in front of the wicket, where it ends as a well hole, which is carried up to the yard level. A cast-iron manhole with a tight lid, such as is used for cistern tops, is used to cover the well hole. When a kiln has been burned off, and is ready to draw upon, a hole is worked through the lower part of the wicket, the lid to the manhole is removed, and the coupling is made between the two with the gooseneck. The latter is merely a heavy sheet-iron elbow, fifteen to twenty-four inches in diameter, with handles for lifting while hot. The joint between the gooseneck and flue is made tight with mud. After all available heat has been taken from the kiln, the gooseneck is removed, the lid put back in the manhole, and the kiln is entirely isolated from the drying system.

There is no possible chance for back draft into the waste-heat flues. The hole in the wicket for insertion of the gooseneck can best be provided for by having a large drain tile or sewer pipe built in upon setting up the wicket. This is then stopped with bricks and mud daubing. On removal of these the balance of the wicket remains in a good, tight condition.

With rectangular kilns, or round kilns having two doors, it is common to keep the fire holes and crown hole closed, and admit the cold air through the door or wicket in the opposite end or side of the kiln, so that the air has to pass through all of the ware on its way through. This is a doubtful expedient, however, especially in the beginning, when the kiln is at its highest temperature. The admission of cold air through the wicket is very likely to chill and crack some ware. It is safer to take the air in, for a time at least, through the fire holes or crown. At the fan it will be found necessary to have a cold air inlet, whereby the hot air from the cooling kilns can be diluted to suit the needs of the dryer.

The Groveport Dryer.—Where the heat is not sufficient from the cooling kilns, a system can be installed whereby a considerable portion of the heat can also be extracted from the combustion gases of the burning kilns as well, without allowing the combustion gases themselves to enter the dryer. The idea is not new, but is very little used in the ceramic industry, and not at all in the roofing tile plants. A plant was installed in 1906 at the plant of the Columbus Clay Product Co., Groveport, Ohio, by W. G. Worcester, in collaboration with W. D. Richardson, of Columbus, Ohio.

The system required two fans, one to create the draft for the kilns and to deliver the hot combustion gases to the heater, and the other to pull the waste heat from the cooling kilns or the heater, or both, and deliver it to the dryer. The system as installed at Groveport provided a double set of flues from the fan house to the kilns. One flue handled the waste heat of cooling only, and its neighbor the gases of combustion. The waste heat was taken from the wicket of the cooling kiln by a gooseneck, and after passing through the flue entered the dryer fan, which delivered it direct into the tunnels of the dryer.

The gases of combustion, upon reaching the kiln bottom, as they would under natural draft, passed into the smoke flue, which was directly underneath the waste-heat flue, being separated from it only by a four-inch fire-brick arch. Some of the heat of the combustion gases was thus radiated through this arch all the time into the hot-air flue overhead, but the bulk of it passed on to the heater.

This was a brick structure, resembling roughly a tubular boiler on a large scale. The hot combustion gases were delivered by the fan into the lower part of one end of the heater, and passed through six-inch iron horizontal gas pipes to the opposite end. They then were turned

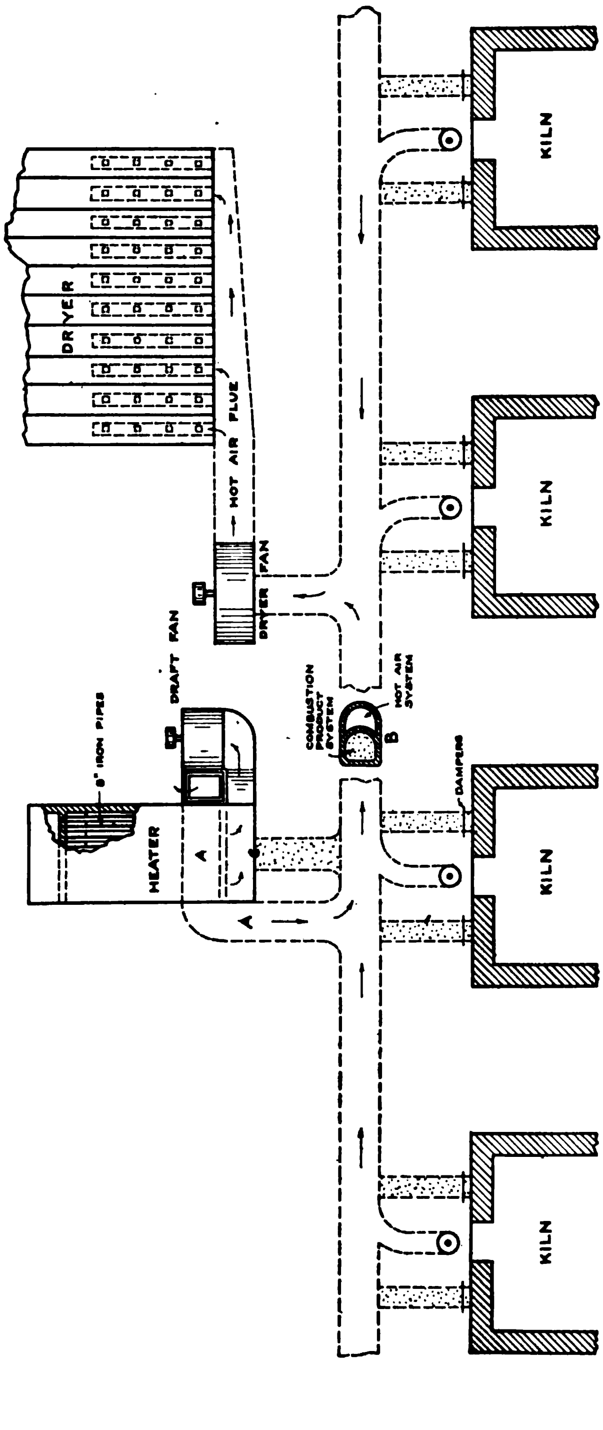


Fig. 146—Ground Plan of Groveport System of Heating Air for Drying Purposes.

back through the upper half of the structure, through more six-inch piping, from whence they went to the fan, which was of the vertical discharge type, with a six-foot wheel. The space surrounding the six-inch iron pipes was also divided into two sections and connected to the dryer fan. Cold air was admitted into the space surrounding the iron pipes at the end where the combustion gases escape, and then passed through the apparatus in reverse direction to that of the combustion gases. It passed out of the heater near where the hot combustion gases entered it, thus coming in contact with hotter pipes the further it traveled in the pipe system . The total travel in the heater for both air and combustion gases was about thirty-five feet, which was found sufficient to take the hottest gases from a burning kiln and cool them to a point where one could easily hold the hand in them at the discharge of the fan. This shows that the heat had been largely extracted from them, but it does not prove that much was actually effective in the dryer.

In Figures 146 and 147 the waste-heat flue system has been left unshaded, and the lower or combustion product flue system has been shaded to enable the plan to be more easily understood. The success of the system is by no means bound up in this particular construction. The flues could have been built separately with equal ease, but it was thought that the placing of the hot combustion gases in the lower set of flues would not only be cheaper in construction, but would assist in preventing the loss of heat from the hot-air flues overhead. The fans were located close together with a view to driving both from the same shaft.

While this system as constructed at Groveport was proved economical as a whole, it developed several objectionable features. First, the metal pipes through which the combustion products were drawn were constantly contracting and expanding with temperature changes, and were pulling loose at their point of passage through the brick partition walls. Even with plastering the joints, using magnesia, asbestos and similar materials, the constant change of size and length was too much, and mixture of the two gas streams ensued. Second, the iron pipes were subject to constant attack from sulphuric acid in the combustion gases. Third, replacement of the metal parts would make the cost high and the shut down of the plant necessary while repairs were in process of installation.

Regenerative Hot Blast Stove Dryer.—The above faults could be largely or wholly overcome by the substitution of a regenerative fire-brick hot stove, such as is used by the iron blast furnaces. This plan would call for the use of two stoves, or possibly more, one of which would be in service heating the air that would be flowing through it, while the other would be taking up heat by the passage of the kiln gases through

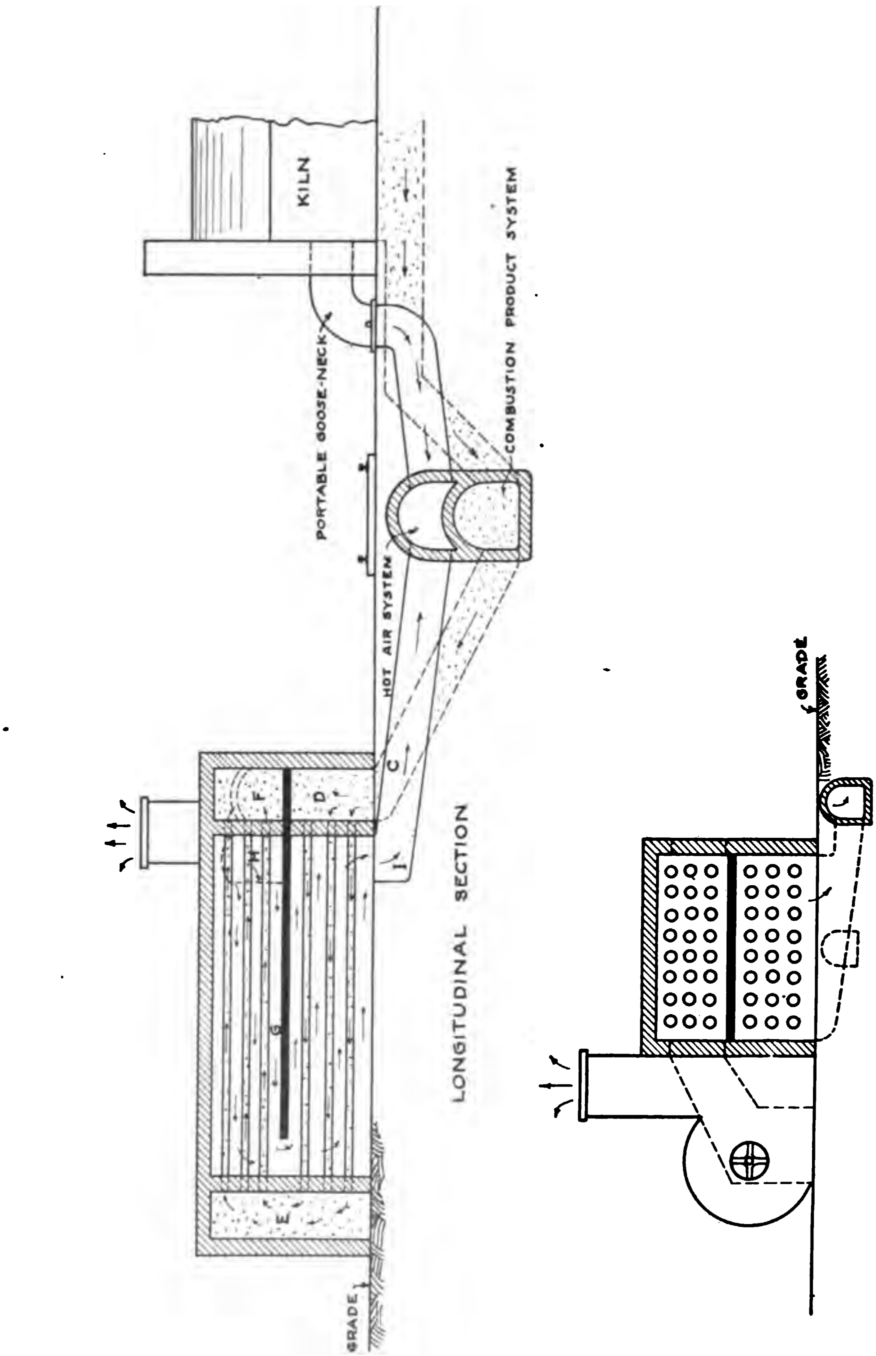


Fig. 147—Sectional Views of the Stove Used in the Groveport System

it. By valves, the direction of the gases could be shifted at proper intervals, and the cool stove reheated and the hot one used for the air supply for the dryer. There is nothing about this plan which is not perfectly feasible from the mechanical standpoint, and well worked out in the daily practice of the blast furnace. The novel feature consists in applying the idea to a ceramic instead of a metallurgical problem. The only difference of operation between the two places would lie in the lower temperature at which the stove would operate in the clay works. Using kiln combustion gases from any ordinary battery of kilns, the temperature would hardly exceed 500 or 600° C. after leaving the kiln and reaching the stove by a more or less lengthy underground flue. These gases would then be cooled to 200 or 300° C. in passing through the stove, before being discharged at the exit end. At this temperature range, 500 to 200° C., there would be danger of sooting the surface of the checker-work of the stove, and if soot did deposit upon the checkers it would speedily defeat the purpose of the stove, as it is a powerful non-conductor. The stoves of the iron furnace are heated directly by the combustion of the waste gases of the furnace, and in each shift any soot deposited would become thoroughly burned out by the red-hot air flowing over it.

The general travel of the combustion gases from the kilns would be through the main flue D to the flues E, E, which in turn connect the chambers, A, A, of the stoves. As noted, the stoves are divided into three compartments, A, B and C, and so arranged that the gases would pass up through the checker work of chamber A to the top of the stove, thence downward through chamber B, under the partition wall and up chamber C to the fan G (see small sketch).

The draft fan, as noted, is placed upon a bridge between the stoves, and connected to each by suitable dampered flues. These flues in turn would be so constructed that when either stove was being drawn upon for heat, cold air would be admitted at the top and would pass down through chamber C, then up through B, and down A, thence out through flue F to the dryer fan and dryer.

While there are many possible ways to arrange the stoves and their flue systems and connections, the one suggested is the most simple and obvious one. If three or more stoves were to be used, some rearrangement would be needed, but the changes would all be easy to make and operate.

The strong argument in favor of the regenerative stove, for utilizing the waste combustion gases of burning kilns, lies in the fact that all parts of the stove coming in contact with the gases would be constructed of fire brick or tiles, thus preventing the destruction of metal parts as in the Groveport system.

There is no reason why the life of the stoves should not be indefinite; thus the first cost would be practically the only one. The fan at the

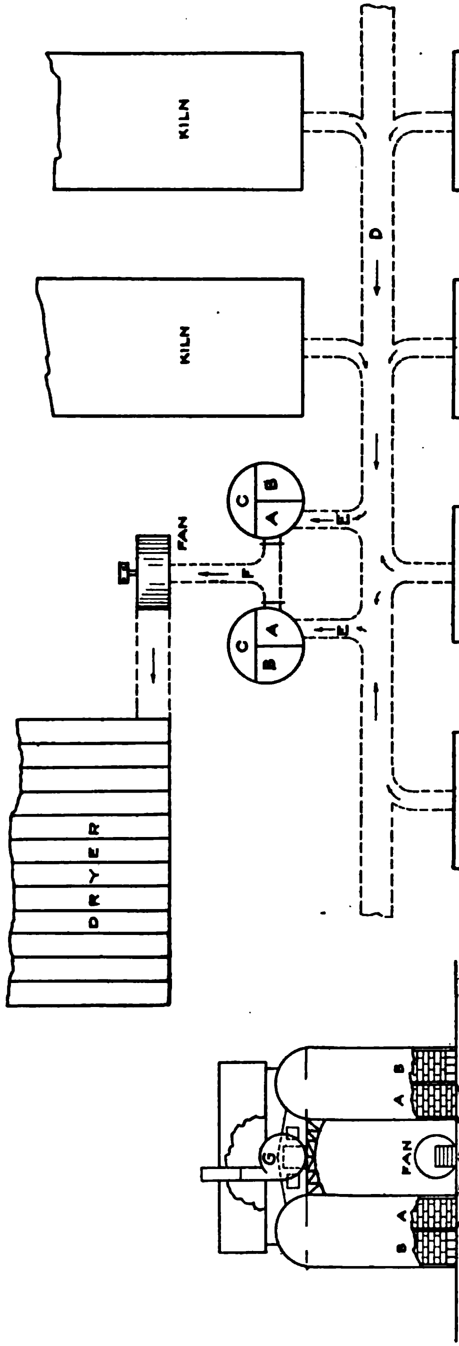


Fig. 148.—Sketch of Proposed Regenerative Hot Blast Stove Installation Applied to Drying.

exit end of the system would necessarily corrode from the sulphur of the kiln gases, but this would happen equally in any system where combustion gases are utilized, and it would be an item of minor importance in any case. It is hoped that this suggestion may be taken up by some clay works and tested. Its chances of success are best, of course, in a plant where a considerable number of large kilns are in use, so that there would be at least one kiln available at all times whose waste gases would be coming off at a temperature of 1,000° or above, reducing the sooting problem to a minimum.

The New Lexington Dryer.—This dryer (Figure 149) is the largest in any of the roofing tile plants of this country. The equipment was furnished by the New York Blower Company, Bucyrus, Ohio, whose drawings were largely used to make up the plans shown.

It will be seen that this dryer is of the double track tunnel type. There are at present thirteen tunnels, or twenty-six tracks. Each tunnel is eight feet wide, six feet high and one hundred and sixteen feet long, holding about thirty two cars of standard make. The ducts under the tracks are eighteen inches wide, and twenty-one feet or three car-lengths long. At the main flue they are thirty-six inches deep, and at the upper end twelve inches deep. The main cross duct is fifty inches by eighty inches, tapering to twenty-four inches by thirty-six inches at the ends. The main flue leading from the cross duct to the fan is eighty inches by ninety inches. The fan wheel itself is thirteen feet in diameter, with a six and one-half foot face, and it is driven by a forty horse power slide valve engine, direct connected.

This dryer is provided with a set of steam coils in connection with the waste heat, so that the drying can be done by either system, although waste heat is the one mostly used.

In Section AA it can be seen that between the fan and the steam coils there is an inclosed space provided with a damper. This damper, when down, shuts off the waste heat system, and when up it shuts off the steam coils. It can be operated so as to allow them both to furnish heat at the same time. In case cold air is needed for dilution, the coils being shut off, the damper is lowered to a point where sufficient cold air is let in to temper the hot waste gases to the proper degree. The dryer is generally operated at about 140° F., though it often runs above this at the hot end.

The main trunk tunnel, leading out to the kiln yard, is six feet four inches by eight feet, connecting to sixteen round down draft kilns, part of which are twenty-six feet in diameter and part thirty feet.

Other Dryers.—The Ludowici-Celadon Company, at Alfred, N. Y., has a waste heat dryer of ten double track tunnels in use. The equipment in this case was furnished by the Buffalo Forge Company, of Buffalo, N. Y. The tunnels at this plant are only seventy feet long, the drying being accomplished in twenty-four hours. At the New

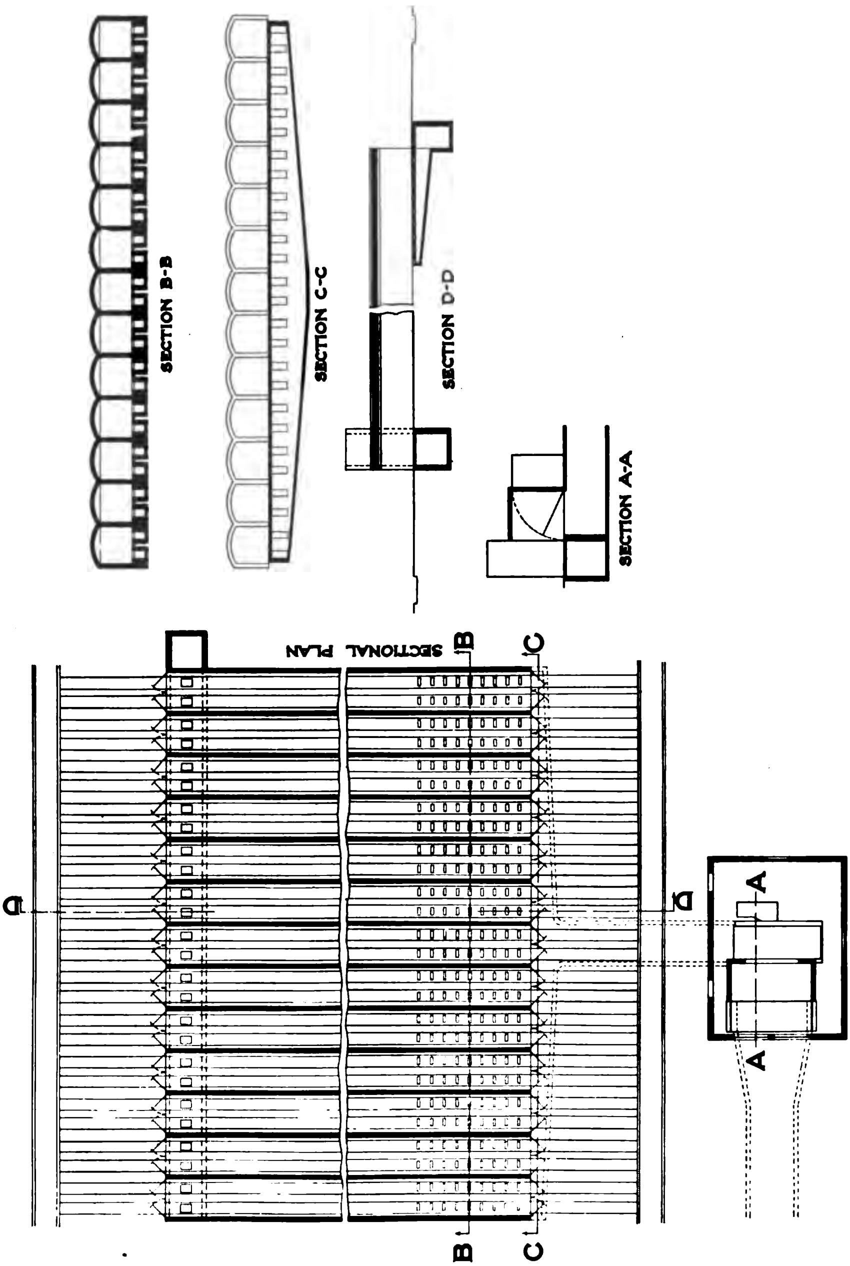


Fig. 149—Waste Heat Tunnel Dryer. Ludowici-Celadon Co., New Lexington, Ohio.

Lexington plant of the same company, the ware is from thirty-five to forty-eight hours in passing through the dryer. The time of drying, however, is regulated by the clay in use. The Alfred Clay Company, of Alfred, N. Y., has a small waste heat dryer consisting of four single track tunnels eighty feet long. The fan at this plant was furnished by The Buffalo Forge Company, of Buffalo, N. Y. The ware was being dried in twenty-four hours.

At the Western Roofing Tile Company, Coffeyville, Kan., the equipment for their waste heat drying system was furnished by the New York Blower Company, Bucyrus, Ohio. They use a small auxiliary furnace, fired by gas, to supply direct combustion products to carry them over times when no hot kilns are available.

In the above cut can be seen the waste heat fan and the gas engine for operating it at night. During the daytime the fan was run by a belt from the main line shaft as shown in the illustration. To the right of the fan can be seen a small furnace built of brick. The large pipe leading down to the furnace is the waste heat flue leading out to the kilns.

Claims for waste heat dryers:

First—That they will dry ware at less cost than any other style.

Second—The first cost is practically the only cost, except for the small cost of operating the fan engine.

Third—It makes a direct saving out of an otherwise total loss.

Fourth—It increases the kiln capacity by cooling them off faster, so that they can be reused earlier. This point is well worth considering.

Fifth—It gives better burns in the kilns, by carrying the heat more vigorously to the bottom at the conclusion of the firing.

SUMMARY.

The foregoing description of the dryers found in use among roofing tile makers brings home the lesson that it is unwise to condemn the equipment of any plant on purely academic grounds, until all of the local conditions are carefully considered. These conditions frequently explain, even if they do not wholly justify, the use of inefficient or poorly designed equipment.

It is, of course, impossible to prescribe the *best* dryer for the roofing tile business. But we may go so far as to say:

First—That for handling the terra cotta and trimmings, a simple room dryer, equipped with ample shelving or rack room, and with provision for maintaining pleasant work-room temperatures at all times, is all that is needed. The source of this heat should be from the waste of other departments, either by building the room above the general dryer, or by use of exhaust steam piping. It is not usually economical

to try to heat a work-room from waste heat of the kilns, unless the latter are located inside of a covered building and the radiations of their exterior can be thus utilized.

Fig. 150—Dryer Fan at Western Roofing Tile Company, Coffeyville, Kansas.

Second—As the source of heat for drying the regular output, the most convenient, elastic and positive arrangement, consistent with high fuel economy, is the use of the waste heat of cooling kilns as the main supply, employing the waste heat of the exhaust steam as the source when no kilns are available. The amount of fuel consumed purely for drying purposes would, with this equipment, be reduced to that necessary to run the fans, and supply such live steam at night as would be necessary in excess of the exhaust of the fan engine, and electric light engines when the latter are used. Such amounts would be small.

It would be possible to equip the kilns so as to utilize the waste heat of the combustion products for drying purposes, but this heat could be used more economically and effectively for water smoking other kilns, etc., rather than for drying. The danger in using combustion products for water smoking purposes, or for direct use in dryers, lies in cooling these gases below their dew point, and thus depositing acid dew upon the wares and scumming them.

Third—The form of dryer in which this most economical heat supply should be applied must depend on the clay. Where the latter is safe and easy drying, the tunnel system, operated as a continuous dryer, with both forcing and suction fans, gives the finest results both

as to speed, quantity and freedom from scum. With clays more or less tender, departure from this type to any required degree must be made. Usually a periodic tunnel will handle a moderately tender clay. If not, a room equipped with tracks will perhaps answer.

Fourth. In dealing with tender clays, the safety of the product is always first, and fuel economy secondary, and it is not to be expected that methods for tender clays will give any high-grade results as to fuel economy, for such methods involve small outlay, slow drying, liability to scumming, and extensive capacity in proportion to output, and hence expensive heat distribution and much heat loss.

Fifth. The use of new fuel, burnt for drying purposes only, with no effort to apply the waste heat of engines or kilns, and especially by such methods as the indirect radiation of hot floors, with no positive provision for creating or distributing draft, represents the lowest grade of practice, and is utterly unjustified on any grounds. The clay cannot require such treatment, for it is severe on a tender clay, and any clay that would stand this would stand better methods. Economy of first cost cannot be urged, for the dryer is expensive to build. Economy of operation cannot be urged, for it is the most costly to operate. Simplicity cannot be urged, for it requires more labor and as much management as a good dryer. In short, it represents only bad management and low intelligence.

Sixth. The selection of a plan of drying involves the consideration of the system of handling the ware: (a) from the machines to the dryer; (b) in the dryer; and (c) from the dryer to the kiln for setting. The economy of the drying cannot be considered apart from the handling system.

Seventh. The use of cars, or some sort of portable racks or pallets, rather than fixed racks or shelves, is consistent with even the tenderest clays, and should never be omitted. The extra handling alone in some roofing tile plants costs more than the whole drying ought to cost.

DRYER CARS AND PALLETS.

Pallets.—The nature of roofing tiles requires that they shall be well supported when first made or taken from the press, and this support must continue until the tiles are dry enough to handle.

All roofing tiles, coming from either auger machine or presses, are far too soft or pliable to retain their shape without the use of a pallet or form. It is not only essential that tiles be supported, but they must have enough freedom of movement to allow for shrinkage while drying.

The choice of materials for use in constructing pallets has been given much consideration and experiment in the various roofing tile plants. So far, wooden pallets have, on the whole, proven the most satisfactory.

on account of their cheapness, lightness, and strength. They also offer good resistance to sudden blows or shocks, if suddenly dropped or roughly handled. Other materials, including heavy sheet iron, cast iron, slate, and wire mesh, have from time to time been used. Some of these are still in use to a small extent.

Taking up first the pallets for flat shingle tiles, the most simple form of all, we find in use at the greater part of the plants the plain lath or wooden pallet shown below.

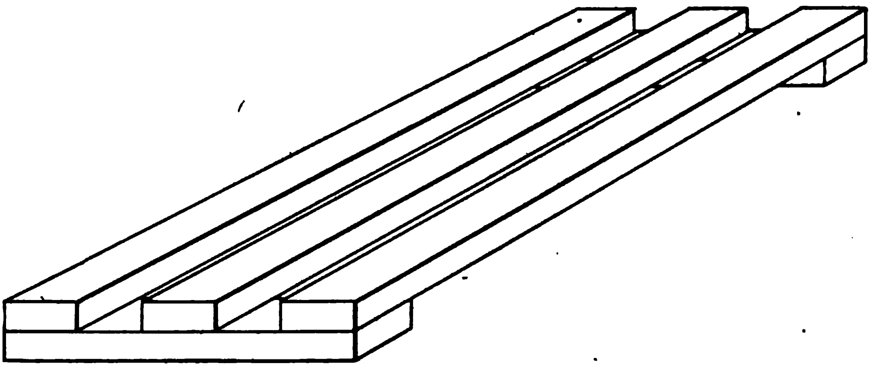


Fig. 151—Wooden Shingle Tile Pallet.

This pallet is best made of white pine or poplar. The two end strips or tie-pieces are about one-half by one and one-half inches, while the main top slats, three or sometimes four in number, are from one inch to one and one-half inches wide by three-eighths inches thick. The length should suit the tile, with about one-half-inch surplus at each end, to permit the necessary play while placing on the rack cars. The whole pallet is securely nailed, and costs in the neighborhood of four or five cents. Hence with pallets sufficient for a three days' run, allowing an output of twelve thousand per day, it will be seen that there is a considerable investment represented. Their rapid rate of deterioration makes it very necessary to get the best.

From time to time, a good straight slate of the proper size has been used, but it has been found very difficult to get straight ones, and the worst feature about them is the breakage which in a year's run is enormous. The high breakage makes them too expensive and their weight is objectionable. At the Huntington Roofing Tile Company, it was found that iron shingle pallets were being used. This pallet was six inches wide, about fifteen inches long and one-eighth-inch thick. Except as to weight, they make very serviceable pallets; they require very little space on the car or in storage, hold their shape well, and if bent can be straightened back again, so that their life is indefinite. For "curvilinear" tiles for domes, it is only necessary to have a number of them bent to the proper curve, and then put the tiles on

the same as though it were a straight pallet. While their first cost is a little above that of wooden pallets, their durability is very much better, and by keeping them protected with good metallic paint they will outlast the wood so much as to make their ultimate cost less than wood.

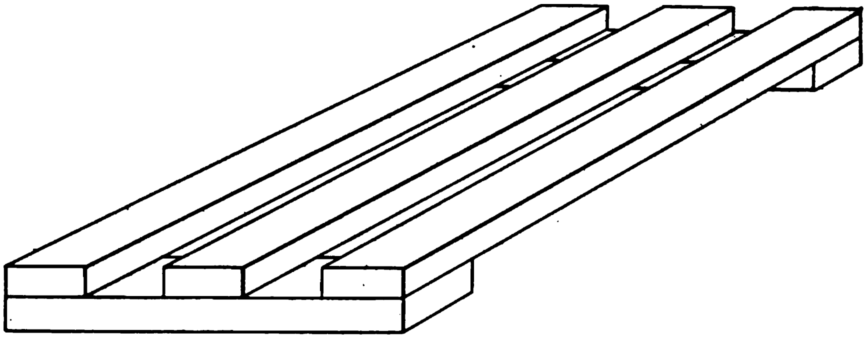


Fig. 152—Interlocking Tile Pallet.

Pallets for interlocking tiles are all practically of one style, viz., plain slatted wooden affairs, in various sizes to suit the tiles. With some designs of tiles, it becomes necessary to increase the thickness at certain points to support irregular parts of the surface and locks, but the main features of the pallets are not changed.

It will be seen in Figure 152 that the interlocking tile pallet is only an enlarged form of the shingle tile pallet. The slats or cleats are usually one-half inch or five-eighths inch thick, and two inches wide. The material is either white pine or poplar, well seasoned and surfaced on both sides.

During the days of the Chicago Roofing and Siding Tile Company, at Ottawa, Ill., a pallet like the above was used, except that the end cleats were put on edgewise, so that they formed legs. The pallets, when loaded with tiles, could then be stacked one above the other for drying. Their dryer was that of the slatted-floor type. commonly used in sewer-pipe manufacture, and the pallets were trucked into the dryer on two-wheeled trucks, and set off on the floor ten to twelve courses high. Hence legs were necessary. For drying on cars or racks, the pallets shown in the illustration are of the proper style.

The most trouble is experienced in providing a pallet for Spanish tiles which will not only hold the tiles true to their curves, but at the same time will allow them to shrink. The pallet shown in Figure 153 has proved the most satisfactory of all.

These pallets are very ingeniously constructed. They are made of a single base-board, about seven-eighths inch by twelve inches, cleated with two strips on the under side. On the left-hand upper side is nailed a strip of wood having a curve to correspond with the curvature of

the tile at that point. On the right-hand side are two strips, the inner one being nailed fast to the base, the outer one loose or movable. It is necessary to have this outer strip movable to allow for the drying

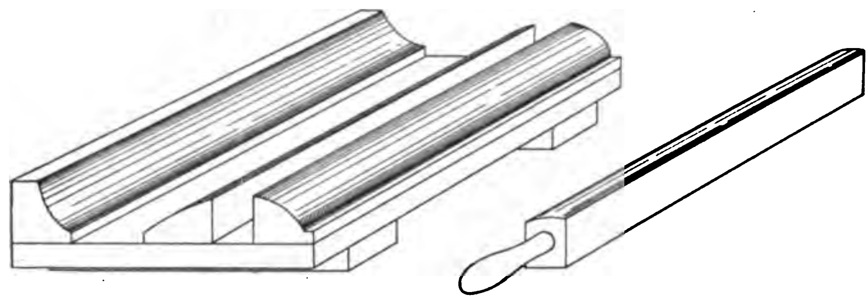


Fig. 153—Spanish Tile Pallet.

shrinkage of the tile. In order to hold the movable strip in the proper position while putting the tiles on the pallet, the false block to the right in Figure No. 153 is inserted, upon placing the pallet ready to be filled. After the tiles are placed on the pallet, usually three deep, the block is removed and the pallet with its load is ready for the dryer. In case the outer or movable block is made fast to the base-board, the tile will be spread or flattened out at that point. If not flattened, they will crack lengthwise of the tile.

Metal pallets of this same general outline have been used, but it was found that they soon lost their shape, and, also, no provision could be made to allow for the shrinkage. Hence, many of the tiles were spoiled in the drying.

For Spanish tiles made on presses, it becomes necessary to construct a pallet which will allow for the head or heel locks of the tile. It will be seen in Figure 154 that this pallet is copied after the form used for shingle and interlocking tiles. The only real difference is that the right hand slat is made enough thicker than the others to hold the roll of the tiles at the proper level, and a slot or groove is cut crosswise of the pallet to provide depth for the heel lock. This slot is made about twice as wide as the lock lug, so that ample room is given for shrinkage.

Each plant finds it necessary to have many other pallets than the ones used for the regular tiles. There are pallets for eave tiles, top or ridge tiles, mitre tiles, tower tiles and various other shapes, all of which must be provided for specially. The number of any one of these special forms is not very large, but the aggregate is very considerable.

Dryer Cars.—The question of dryer cars has been worked over about as thoroughly as the matter of pallets. Natural selection has reduced the surviving types to about two forms, both of which are rack cars. On one, the cross racks or strips are movable or loose, while on the other

they are fixed. A rack dryer car, to meet the demands of a roofing tile plant, must be easily adjustable to suit the various spacings needed for the many sizes of tiles made.

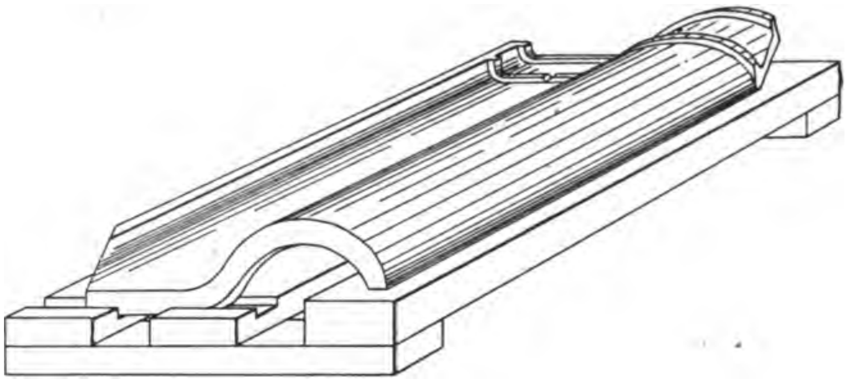


Fig. 154—Pallet for Press-made Spanish Tile.

There are in use at the present time in the various roofing tile plants of the country about two thousand five hundred cars, the greater part of which have been made by standard car builders. Among them were the following First, The Cleveland Car Company, Cleveland, Ohio, having the largest number in use; second, The Atlas Car Company, Cleveland, Ohio, with the next largest number in use; third, The Ohio Ceramic Engineering Company, Cleveland, Ohio; fourth, The American Clay Machinery Company, having cars in two plants. Two roofing tile plants have built or assembled their own cars.

The average dryer car for roofing tile is of twenty-four inch gauge, the rack is thirty-six inches wide by seven feet long and a height over all of about six feet.

The racks are divided either into two or three sections. The number of shelves that are put in a section depends on the tiles manufactured, most of the cars holding from one hundred and fifty to two hundred interlocking tiles, or two hundred and fifty to three hundred shingle tiles.

The main truck of this car may be of any make. The uprights are of narrow channel iron, usually two inch, and are riveted to the truck, and secured by gusset plates as shown. At either side of the top, a longitudinal tie bar of iron fastens the uprights together, while at the ends it is usual to put on cross braces, as shown by the end view.

Running across the car, from upright to upright, and riveted to the same, are one inch angle irons which act as brackets upon which the one inch wooden strips rest. These wooden strips are loose so that upon loading a car at the press, the strips on the side nearest the press are left out, thus allowing the placer to reach more easily the opposite

side of the car with the pallets. When the further side of the car is filled, he puts in the strips on the near side and fills them. It is usual to have about three rows or tiers of pallets, running crosswise of the car, so that it would be difficult to reach through and put the further row in place.

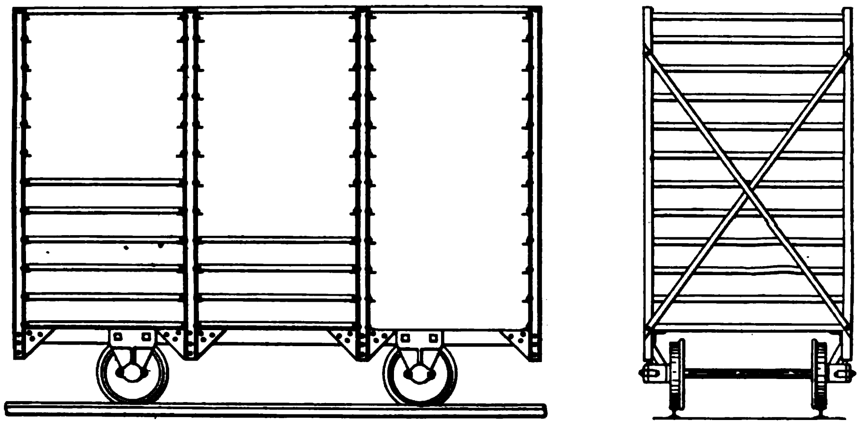


Fig. 155—Three-Section Dryer Car, with Loose Racks.

The objection to this style of rack system is that there are too many pieces to handle, not only at the press, but in the kiln. This point has been overcome by some in having two section cars with strips reaching the full length of the car. The trouble in this case is that the strips cannot be taken out of the car without pulling them out from the end, which takes up much time.

Probably the best style of rack car, where loose strips are used, has a rack containing loose sections, and has the strips reach half the length of the car. They can then be easily taken down, or put up, as occasion requires.

Where a plant is running continuously on one style of tiles, a rack car can be devised, as has been done by the Ludowici-Celadon Company, at New Lexington, Ohio, which comes very near meeting all requirements. In this car the strips are fixed.

It will be observed that this car is constructed much like the one just described. The upright members are made of channel iron, well braced and riveted. Instead of the one inch angle irons being fastened to the uprights, and forming supports for wooden strips, they are carried by two inch channel irons extending lengthwise of the car on either side.

The one-inch angles are held in position by having a short section of pipe put under the top leg, to act as a spacer. The rivets which hold the angle pass through the pipe washers also, making a very solid, well

built car. The pallets are slid in on the one-inch angles, the first one being put in part way, then pushed over by the ones following. The pallets are put in four wide, filling the width of the car.

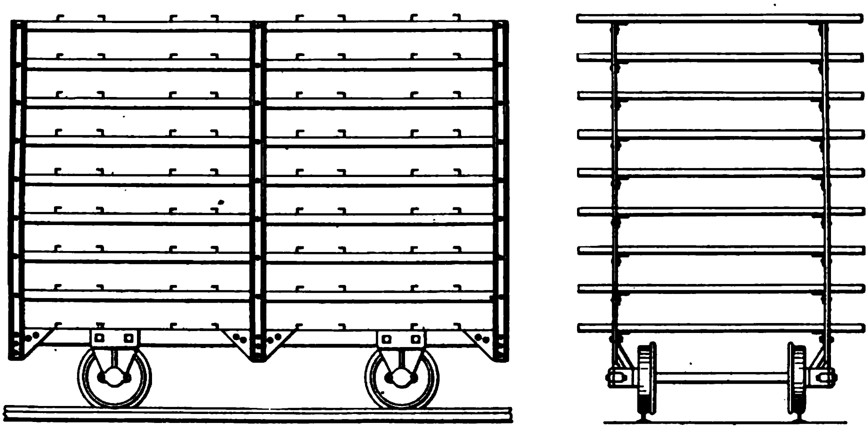


Fig. 156—Two-Section Dryer Car with Fixed Racks.

In the case of the car having loose slats, the tiles are placed crosswise of the car, and hence at right angles to the flow of air in the dryer, while in the car having tight slats, the tiles are placed so that they are lengthwise of the car, hence the flow of air in the dryer passes lengthwise of the tiles and not across them. This latter plan is probably the better, for the ends of the tiles are more able to stand unequal strain from sudden drying than the sides.

The main objection to the car with fixed racks is the inability to adjust it to suit the various styles of tiles made about the plant. If sufficient cars can be supplied to handle all necessary varieties, it is much better to use fixed racks. The value of a dryer car will vary materially with the style and the kind of rack wanted, but a fair average price is about $20.00 each.

In selecting a car the bracing and the rack construction should be well looked to. The axles should by all means be equipped with roller bearings and automatic oiling facilities. The roller bearings should be made of true, perfect cylinders or rollers. The kind that are sheared from rod iron or cast, as are used on the cheaper cars, are very unsatisfactory. The sheared roller is sure to be flattened at the ends, from the pressure of the shears in cutting, and hence they can not run easily. The boxing should be such that the oil cannot escape as soon as it becomes warm in the dryer.

The entire car should be well coated with a good metallic paint, especially if the cars are to be used in a waste heat dryer, for the corroding action of even diluted sulphuric acid while in the damp atmosphere of the dryer is very severe on unprotected iron.

It can be positively stated that roofing tile companies cannot make their own cars as cheaply, or as well, as the firms that are making cars all the time. In the first place, no ordinary clay works has the proper

Fig. 157—A Home-made Car.

tools for doing the work. Their men are not skilled in such labor. A plant may be able to save a trifle on the first cost of the cars, but the loss comes in later in the short life and extra labor to use the car. In other words, every man to his trade, and always at it.

CHAPTER VIII.

SETTING OF ROOFING TILES.

The first thing to consider in connection with the burning of a clay ware of any sort is the proper mode of placing the ware in the kiln so that each piece may receive the heat treatment necessary to develop its strength and color and at the same time not be damaged by sinking out of shape under its own weight.

The process of placing is universally known as "setting" in the United States, and it is one of the most important things which a successful clayworker has to consider. The difference between expert setting and ordinary setting may easily make the difference between success and failure of a whole establishment. It is a place where craftsmanship counts very heavily in any clay working enterprise. The problem of setting roofing tiles is more akin to that of setting terra cotta or pottery than it is to bricks, sewer pipes or other crude forms of ware. The distinction hinges on the question of the ability of the ware to sustain weight. In the case of bricks or pipes the ware is self-supporting. Bricks, being of thick, heavy cross-section, are admirably designed to support great weights, even when approaching viscosity by vitrification. Bricks are set twenty-five to thirty courses high, without any supports whatever when firing to vitrification. When firing only to good building brick hardness, forty-five or even fifty courses are piled up without supports. This corresponds to a crushing pressure of from twenty-five to thirty-five pounds per square inch on the lower courses, owing to the uneven distribution of the load, and to the fact that all parts of the bricks are not carrying weight. This load must be borne not only by the dry bricks, but also when the bricks are softened by steaming in the water-smoking stage of burning and when softening from heat during vitrification.

Sewer pipes are usually placed four or five tiers high, with about one-half of the above pressures, but their shape is less favorable for resisting pressure.

In the case of wares of thin cross-section, like roofing tiles, it is impossible to make the ware carry its own load after the manner of bricks, provided it is desired to develop any great amount of vitrification in the firing. Warpage and deformation are certain if the tiles are so placed that they are free to move and are called upon to bear any but trifling weights. Some forms of roofing tiles which are not vitrified can be treated more roughly than the average.

The methods employed in setting roofing tiles may be divided into three general classes:

1st. Those using kiln blocks for supports.

2d. Those using no supports.

3d. Those using saggers.

There were eight plants using the supports, and five plants were found using no supports. One plant, now defunct, had been using saggers. The plants not using supports are making porous or soft-burnt tiles only.

SETTING WITH KILN BLOCKS.

Blocks.—The blocks used for kiln furniture in the roofing tile business are most usually made of No. 2, or easily vitrifiable fire clays. Sometimes, to make them harder, so as better to resist handling, various per cents of ordinary red burning clays are added.

In dimensions the blocks are, of course, made to suit the sizes of tiles manufactured. The thickness of the block is usually two and one-half inches, remaining the same for all sizes. The blocks mostly used for Spanish tiles are eleven by fifteen by two and one-half inches. For shingle tiles the horizontal blocks are as a rule the same as the Spanish blocks, but the risers, or uprights, are seven by eleven by two and one-half inches if the shingle tiles are six inches wide and are set on edge.

While some of the roofing tile plants buy fire clay and make their own kiln blocks, it is in most cases better to purchase the blocks from the fire brick companies that are fitted for handling this class of work and this is most commonly done. On inquiry, The Chas. Taylor Sons Co., Cincinnati, Ohio; The Harbison-Walker Co., Portsmouth, Ohio; The Stowe-Fuller Co., Cleveland, Ohio; the Federal Clay Products Co., Mineral City, Ohio, were found to have supplied the bulk of the blocks used by the roofing tile manufacturers, but the ware is of a kind that any fire brick manufacturer could readily supply.

The kiln block should be well made; it should be straight, with sharp corners well filled out, true to size, and burned to a point where it will stand rough usage without undue crumbling along the edges. These blocks are not destroyed by the heat they are called on to endure, but by the constant handling in setting up and taking down each time the kiln is fired.

In preparing a kiln for setting, should it be a new one, the first thing done, starting at one side in round kilns or the end in rectangular kilns, is to place ordinary fire bricks in rows upon the floor of the kiln. The first row is placed about three inches from the wall or end of the kiln. Each individual brick is placed on its side, and is so spaced from its neighbor that the kiln blocks to be used will reach from the center of one to the center of the next. This will leave five or six inches be-

tween the ends of the bricks. They are thus continued across the kiln. A parallel row is placed so that the surfaces of both rows will be covered by one of the kiln blocks. After both rows of bricks are down, blocks are then paved on them from end to end. (See Figure No. 163.)

After the first stand is laid out, a five or four inch space is left, and a second stand is put down parallel with the first. In this manner the entire floor space of the kiln is laid off. The object of this false floor is to elevate the position of the lowest tiles above the main floor, so that they shall not be cut off from contact with the currents of hot gases as the latter are deflected over the floor in finding a passage out. Ware set on the actual floor would be apt to be spotty and irregularly burnt.

Fig. 158—End or Bench Braces in Round Kiln of Spanish Tiles.

The setter now stands a riser block on the first stand of bottom blocks, and against the left hand wall of the kiln. Then he places tiles, which are handed to him two at a time, against the riser block. After the required number have been placed in a pile, a second riser is put in at the point where the two floor blocks meet (see Figure No. 163), and a cover block is laid across, connecting from the center of the first riser to the center of the second. The rectangular space thus created is called a "box." A second box is made and filled, using the second and third risers and a cover tile. Thus the work proceeds.

A vertical tier of boxes, reaching from the floor to the top of the setting, is called a bench or stand. The latter is the better name, as "bench" in other clay industries refers to a horizontal division, not to

a vertical one. When the first stand reaches a level where the setter can no longer conveniently reach to put on more boxes, he starts the second stand. After one or more courses of boxes has been placed across the kiln in the second stand, the setter uses this as a platform to carry up the first stand still higher, and so on, until the kiln is filled.

In round kilns, at the intersection of the stands with the walls of the kiln, it becomes necessary to put in braces against the stands at each course, to keep them steady and from toppling over endwise.

It will be seen from the figure that these braces are made by using two kiln-blocks, turned at right angles to the other risers, at the beginning of the last box. Considerable space is thus lost, but it affords a secure way of holding the risers in place.

To hold the benches from reeling or falling over sidewise, no provision is made except to keep the stands perfectly plumb, so that no tendency to fall is developed.

The foregoing gives a general idea of the method used in most roofing tile works. It will be found that the various styles of tiles, shingle, interlocking and Spanish, require some modifications of treatment due to their form and there is some element of choice also; i. e., shingle tiles are sometimes set in different ways.

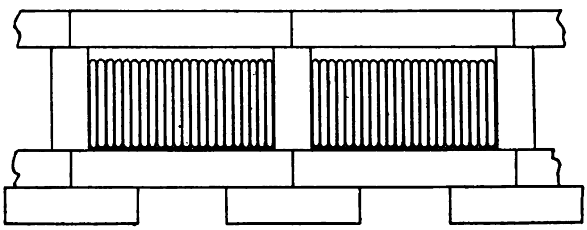


Fig. 159—Ordinary Way of Setting Shingle Tiles.

Setting of Shingle Tiles.—The setting of shingle tiles appears to the outsider the easiest and safest of all, but in setting, as in manufacturing, it is about the most difficult. The actual handling or placing is easy and simple; the skill comes in knowing the best method of placing to prevent side-checks, center-marks and warpage. There is, however, no single best method. One plan will best suit one clay, and an entirely different one some other clay. In the majority of cases, the plain ordinary setting shown in Figure 159 is used, on account of its simplicity and cheapness.

The tiles are placed in the boxes, on edge, and packed as tightly together as possible. It is necessary to pack them snug, in order to prevent them from leaning over sidewise as the shrinkage takes place. In some instances, a little sand is scattered under the tiles to assist them in drawing together during shrinkage, but more frequently the blocks are left bare.

While this style of setting tiles is largely used, it has certain objections:

First. The packing of the tiles in this manner makes to all intents an almost solid block of clay, six by twelve by fifteen inches. If a really solid block of clay of the above dimensions were to be burned,

Fig. 160—Showing High Shrinkage in Boxes of Burned Shingle Tiles.

it would be considered a very difficult task, and very truly so. It is also true to nearly the same degree with a mass of shingle tiles, set solid. Many of the standard roofing tile clays have been shown to contain considerable amounts of carbon, which must be very carefully burned out, at low temperatures. The thicker the individual piece or the more solid a group of pieces, the more difficult does it become to get rid of this carbon from the center of the mass. The best burning temperature for this carbon is at a rather low, clear red heat

(750° to 800° C.), 1380° to 1470° F. Higher temperatures increase the danger of center-marking, and lower temperatures delay the process unnecessarily.

A second difficulty is that of securing contemporaneous shrinkage in large masses. As the temperature increases, the top of a block of tiles (in a down-draft kiln) will become hotter than the bottom or center of the mass. Therefore the shrinkage will start first on top, and unless time be given to allow the heat to soak into the block of tiles side-checks will result.

A third trouble with this method of setting is caused, especially in clays of high shrinkage, by the tiles becoming separated and leaning over as the shrinkage takes place. It is not unusual for the shrinkage to amount to a full inch in a single box, so that the deflection of the tiles from the vertical is sufficient to allow them to warp or twist.

In the case of a clay low in carbon, properly prepared, and of not excessive shrinkage, it is perfectly possible to burn shingle tiles in this manner of setting in perfect safety.

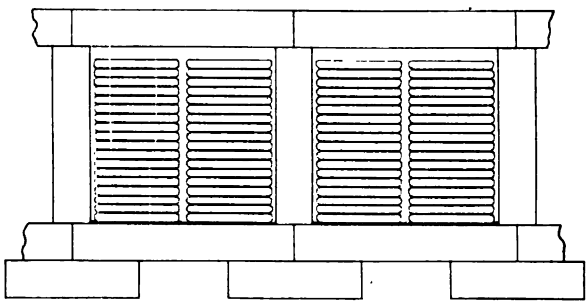


Fig. 161—Method of Setting Shingle Tiles Flat, in Use at Murray Roofing Tile Company, Cloverport, Ky.

The flat method of setting shingle tiles is shown in the above illustration. The mass of tiles is set flat, one on the other, instead of being set on their edges. Two blocks are set in one box. This method of setting was in use at the plant of the Murray Roofing Tile Company, Cloverport, Ky., at the time this plant was visited (July, 1908). While there are some good features about setting shingle tiles in this manner, there are at the same time some bad ones.

In the first place, the block upon which the tiles are placed must be perfectly straight, or sand must be provided upon which to bed the tiles. This method of setting is faster than the edge setting. Less kiln blocks are used, and no attention need be given to keeping the tiles from falling over. The fact that both edges of the tiles are exposed to the kiln gases, makes the liability to side-check less than by setting on the edge, in which case the upper side is sure to heat much faster than the lower.

The danger of center-marks is for the same reason a trifle less, but it is still great. One of the strongest points in favor of this method of setting is that the tiles upon reaching a fair state of vitrification will have a tendency to straighten out any slightly warped or bent tile by their own weight. Increase of the temperature increases the danger of warpage where the tiles are on edge, but decreases it as the heat increases in the flat-setting method.

If the tiles happen to be already warped when piled or blocked up, it will be found that considerable breakage will result from the weight on the warped members.

With nice straight tiles, and clay of average quality or above, this method of setting is unquestionably the best of any seen for shingles. It takes, however, ten or twelve days, from the time of lighting the fire to closing down, to safely burn a kiln of tiles set in either of the preceding ways, while other shapes of tiles can be burned in half the time or less, because the setting is more open and free. The relative tonnage per kiln would be much in favor of the shingle tiles, and when the fuel consumed in firing two or more kilns of other shapes in short burns is balanced off against the quantity of fuel consumed in firing the shingle tiles in their long burn, the probability is in favor of the fuel consumption per ton being less for the shingles.

On the other hand, on account of the heavy overlap of shingles it is likely that the fuel cost per square would be heavier than for interlocking or Spanish shapes.

Another method of setting shingle tiles has been used to some extent in a few plants, where it has been desired to burn shingle tiles in the same kiln with other styles, or, in other words, to hasten the time of burning. The plan as used a number of years ago was to set the shingles only on the top of the stands or benches, and not in boxes. Starting at the side of the kiln, on top of the stand, the first shingle was placed flat on a light bed of sand. The next shingle was placed in the same manner as the first, parallel to it but with an intervening space of about four inches. The third tile was placed in the same way, and so on, clear across the kiln. Upon reaching the further side, the setter returned and placed a second layer of tiles over the first, but instead of stacking the tiles one on the other, they were placed so as to cover the spaces, each tile overlapping the edges of those beneath by about one inch. The setting continued thus until ten or twelve layers had been laid down. A couple of tiles were lost on each course owing to "stepping in" the ends.

This method had some very good features: First, the tiles were set very open, allowing the kiln gases to circulate among them very freely. There was consequently no trouble from center marks, as the central area of each tile was exposed; second, the chances for side checks were reduced to the minimum, as the sides overlapped and car-

ried the weight, thus forming the thickest part of the setting, which would naturally shrink more slowly, thus giving the center of the tile the advantage and creating a tension there, rather than on the edges.

The objections to this method of setting are, first, only a limited number of tiles can be placed in each kiln (twelve to fifteen courses); second, being at the top, they were exposed to the direct flash of the flames, and many were lost by flashing and overburning.

An outgrowth of the above method of setting shingle tiles has been shown in the following cut.

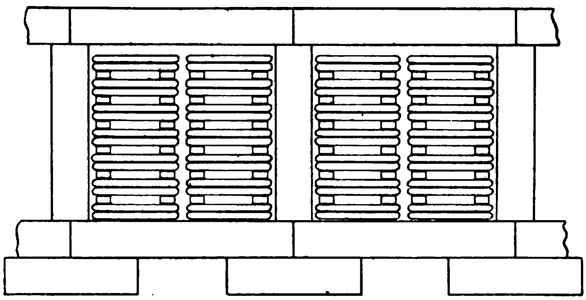


Fig. 162—Waste-Strip Method of Setting Shingle Tiles.

It will be seen that this method is a combination of the second and third methods, with the difference that straps, or narrow strips of newly made shingle tiles, are used as spacers.

The setter is provided with a trowel and a pallet full of tiles fresh from the machine; with the trowel, he cuts the narrow strips which he places as shown, lightly bedding each pair of tiles down, as he places them on the straps. Slight irregularities of the tiles are thus taken up by the yielding of the damp straps.

The advantages and disadvantages of this system are obvious: The dangers of side checks and center marks are obviated as in the previously discussed methods. The time of burning is greatly shortened from that required to burn shingles set in the ordinary way. And, of great importance, the entire kiln can be set with shingle tiles if necessary, or only portions, as may be desired. On the other hand, it is the most costly method of setting shingle tiles, as it requires so much time to cut and place the straps. The straps also consume heat, and are a loss at the end of the burn. The only use that readily could be made of them would be to grind for grogging the body.

About one-third of the space is lost in each kiln by the use of straps, which runs up the fuel consumption per ton. Lastly, the drawing or unloading of the tiles from the kiln is more costly, it being necessary to separate the tiles and straps. Many of the straps are badly checked or broken into short lengths. These pieces fall to the floor and get into

the flues of the kiln, thus causing extra expense in cleaning out the kiln bottoms oftener than would be otherwise necessary.

For the general manufacture of shingle tiles, this method of setting could hardly be recommended. In special cases, where only a few shingles are required to go with other styles and must be burned at the same time, it is certainly the most secure method of getting a high yield and good quality. The additional cost is to be endured under these circumstances.

Setting Interlocking Tiles.—There is practically only one way of setting interlocking tiles, viz.: in the "boxes" previously described, as built from kiln blocks. The method is very similar to that of setting flat shingles on their edges or sides.

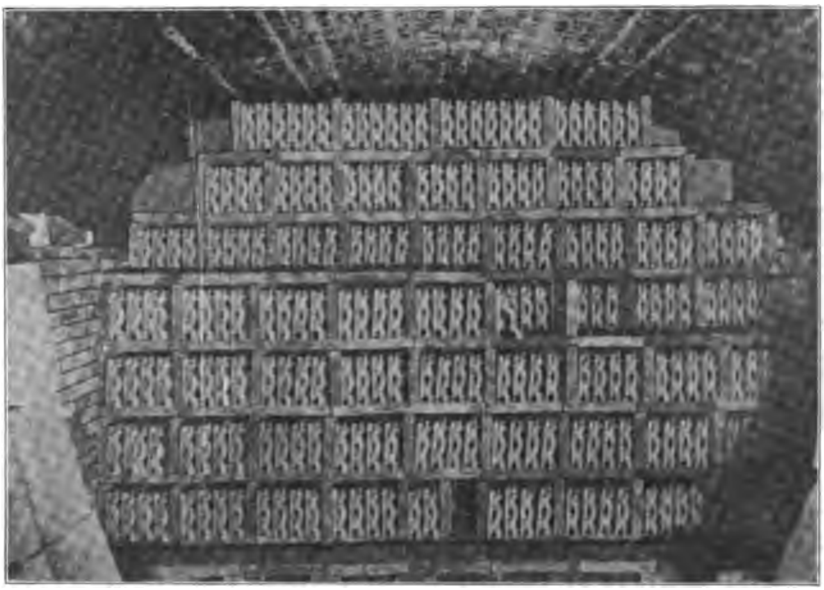


Fig. 163—Kiln Partly Set with Interlocking Tiles, Western Roofing Tile Co., Coffeyville, Kansas.

The interlocking tiles, however, are nested by reversing every other tile to make them fit more snugly together, i. e., the head lock of one tile is turned to mesh with the heel lock of its neighbor. All interlocking tiles are handled in this way in pairs, from the time they are dry until they are shipped.

By referring to Figure 163, it will be very easily understood how the tiles are set. The illustration is of a rectangular kiln; below the top of the bag walls no side braces are necessary to support the benches. Above the bag walls extra heavy blocks made for the purpose are used.

It is readily seen that in tiles with as much open space between them as the interlocking must have, very little if any trouble will result

from center marking or slow oxidation. For the same reason, and also on account of the shape, side checks are almost unknown.

Setting Spanish Tiles.—In setting Spanish tiles, there are two methods, one for auger machine tiles, and the other for the pressed tiles. While the setting is not widely different, the auger-made tiles require more care and experience. The auger-made tiles do not have the end locks or ribs, so they are much more apt to warp or twist. The locks very materially strengthen the press-made tile.

By referring to Figure 164, the general method of setting auger-made Spanish tiles can be seen at a glance. The tiles are placed on end in the boxes, in pairs, a narrow space being left between each pair. If the tiles were set tight, it would make a cubic mass of clay 11 x 12 x 14 inches, which would be very difficult to burn safely.

It has been found by experience, that for most clays, it is not safe to stand the tiles directly on the kiln blocks. Some cushion or yielding material must intervene. Should the tiles be placed directly on the blocks, the lower end of the roll will be flattened or spread out during the burning. This trouble comes from the inability of the tiles to shrink freely. It will be remembered that precautions have to be taken in drying this kind of tiles to prevent the same trouble there.

The liability to spreading of the rolls of the tiles, during burning, will be more intensified if the tiles are not set perfectly plumb. If a tile leans, it will throw more weight on the corner, or roll, and thus cause it to spread more. By placing a blank (called a strap) of damp clay on the block before setting a tile, the trouble is usually entirely obviated. The straps that are used are flat pieces of the same clay as the tile, about five-eighths of an inch thick by eleven inches wide and fifteen inches long. These blanks are run at such times as is necessary to have them fresh; they must not be too dry, or they fail to accomplish their end.

In operation the setter places a strap on the bottom block of the box to be filled. As the tiles are passed to him, a pair at a time, he carefully stands them, as shown in the cut, against the last upright block. The next pair of tiles is set about one-half inch from the first pair and so on until the box is filled. The soft strap underneath makes it possible for the setter to get each pair of tiles vertical. Should the end of the tiles be irregular, it will be taken care of by the pliability of the strap. By examining the cut closely the straps can be seen under the tiles.

When the tiles have all been carefully set in the box, the setter takes an extra strap, and cuts three strips one inch or more wide from it. These strips, also called straps, are equally spaced across the top ends of the newly set box of tiles. With a trowel they are spatted down, so that they mesh into the openings between the tiles to a depth of one-fourth inch or more. This is done to hold the tiles at the proper distance

apart, and to prevent them from leaning or falling over, as they otherwise would be very likely to do.

When the kiln has been burned, the tiles and straps separate very easily; no trouble ever comes from this source.

At different times sand has been tried to take the place of the clay straps, but it has not been successful. The movement of the kiln gases will draw it away from under the outside corners of the tiles, and allow them to sag. Also, the sand very soon chokes up the kiln flues.

While the making and using of straps is an added expense, it is necessary, because it has been found next to impossible to burn the tiles safely in any other way. With clays of exceptionally low shrinkage, or where the vitrification is not carried very far, it may be possible oc-

Fig. 164—Setting of Auger-made Spanish Tiles. Cincinnati Roofing Tile & Terra Cotta Co., Cincinnati, O.

casionally to avoid their use. The setting of press-made Spanish tiles differs from that last described in that straps are not used. The tiles are placed on end in the boxes, with the top end down. The first one is set as tight against the riser as possible, the second is set tight against the first, and so on until the box is filled. The next riser is then put up, the cover block laid on, and the setting of the next box begun. Nothing is used to bind the tiles together.

In some cases, where the shape or locks of the tiles will permit, they are nested in the box, with every other tile reversed, end for end. This, however, will depend on how they will nest best, the complete utilization of the space being the object in view. It is impossible to set press-

made Spanish tiles so tight that they will center-mark. At best they are rather bulky in the kiln; it is impossible to set more than about two-thirds as many tiles in a given space as can be done with the auger-made Spanish tiles.

The reason that press-made tiles do not need to be set on straps is that the strong lugs, or locks, on the ends stiffen the rolls of the tiles and prevent their warping.

SETTING ROOFING TILES WITHOUT KILN BLOCKS

As stated before, there are five roofing tile plants that are setting their ware without the use of kiln blocks, saggers or other means of support.

In foreign countries this method of setting is used almost exclusively; the use of supports is familiar to them, but they do not care to make much use of this plan. In the European plants it is the general practice to burn their product only till it is weather proof, and their ware is what is called in the United States "porous" ware. It is therefore quite possible to set such ware without supports. If producing real vitrified ware, such as many of our American plants are doing, they would be compelled to use kiln blocks or other supports.

The situation as explained for European plants is exactly the case with the five plants in this country that are not using supports. They are all producing porous ware, and they could not set their ware as they do if it were to be carried to anywhere near complete vitrification.

By examining Figure No. 165 it will be seen that on the floor of the kiln are placed three courses of fire bricks, cross-hacked and very open. This is to allow the hot gases to distribute over the floor more evenly.

Beginning on these bricks, the tiles are placed on their side in packs or bunches of ten each. The first pack is parallel with the kiln walls, the next pack is reversed, and so on. It is necessary to wedge them tight at the side of the kiln, so that there can be very little chance of their rolling.

Upon starting the second course, the first pack is turned at right angles to the pack below it; thus every other pack is alternated from bottom to top, as well as from side to side. The ends of the tiles in the separate stands come close together, so that the chance of rolling in this direction is also reduced. In the case shown the tiles are set eight courses high. The spaces between the bags are filled by reversing the direction of the rows, as can be seen behind the man on the left side of the illustration.

In drawing the kiln, the bricks on the floor are taken up and piled in the spaces between the bags after the tiles have been removed. Thus

Fig. 165—Kiln of Interlocking Tiles Set without Supports, National Roofing Tile Co., Lima, Ohio.

Fig. 166—Doorway of Kiln Filled with Interlocking Tiles, Ludowici-Celadon Co., Ludowici, Ga.

they are out of the way of the cars in setting, and are placed only as fast as new stands are to be begun.

In this plant it will be seen that the tiles are set directly upon the floor. The small opening at the floor line is the "peep hole" for observing the heat distribution and for draw trials or cones. It will also be observed that very few tiles are reversed—just enough to steady the benches. Where it is desired to burn glazed ware and is necessary to keep the ware from sticking together, a combination of the two methods is employed. The glazed ware is placed in boxes in the lower part of the kiln, and the open setting without supports is used for the unglazed wares on top of the boxed courses.

In this case, shown in Figure 167, fire bricks have been edged on the floor of the kiln, and upon them boxes made of rectangular fireproofing blocks have been placed. The boxes extend down both sides of the kiln, and then across the kiln with each bench.

The regular setting, without supports, begins on the top of the boxes, and continues six courses high. Tile-packs set crosswise for braces are placed about every twenty tiles. The tiles which are placed directly over each other are not exactly parallel with each other, but are set at slight angles, reversing with each course. This mode of setting is similar to what is known as "skintling" in brick setting. It avoids any opportunity for the tiles above crushing down between those below, and also prevents sidewise rolling in the stand.

SETTING OF ROOFING TERRA COTTA.

The roofing tile manufacturer, as a rule, sets his terra cotta trimmings in the odd space that is left after the kiln has been set as compactly as convenient with the regular shapes. This extra space is most usually found on top, where the terra cotta is exposed to the most severe heat treatment, and where it is most likely to be ruined. This ware, which has cost the most to make of any produced in the plant, should be given the most favorable opportunity to pass through the kiln safely, rather than the least favorable.

The reason that the terra cotta is as a rule placed on the top of the benches is on account of its large size and irregular shape. Hip rolls and much of the cresting can be set in the ordinary boxes, but often at great loss of space. The finials are too large and ungainly to go into regular boxes, and therefore are placed on the top.

The method of setting finials is clearly shown in Figure 168. They are placed on the flange or cresting end, and the ball or head is supported by the low pile of kiln blocks or brick, with a damp strap of clay on top so that the finial can shrink freely. Gable finials stand on end. Special shapes and odd ware has to be set as best it can. An effort should always be made to support it equally in all parts. Large tower finials

are always burned with the bell up, and the small end down, the supports being built up under the bell.

Instead of placing the terra cotta on the top of the kiln, it would seem the rational thing to provide large kiln blocks of a suitable size to accommodate it, and then set these large boxes in the center of the kiln where the terra cotta would get the most favorable treatment. In fact, this is being done at one plant at the present time.

Fig. 167—View in Kiln at Detroit Roofing Tile Company, Detroit, Mich.

The setting of terra cotta in the plants where porous ware is made is a more simple proposition from the fact that there are no boxes to limit the number that can be nested together.

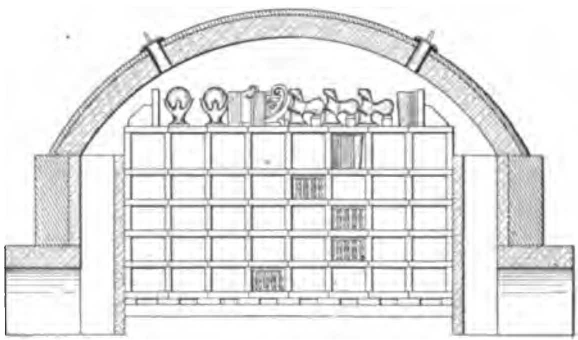


Fig. 168—Drawing of Typical Terra Cotta Setting.

In Figure 169 it will be seen that three courses of loose brick work are set on the floor, then five courses of regular tiles, upon which are placed two layers of cresting. Then, to protect these courses of trimmings, a layer of regular tiles is placed above. Some precaution is taken in this plant to protect the expensive ware, but in many of the plants producing vitrified ware, no shield or protection whatever is given.

In this illustration it will be seen that the tiles start on the floor, no loose brick work being used. *First*, there are three courses of interlocking tiles, then two courses of Spanish tiles, then the special shapes, and finally a course of interlocking tiles to protect them, the latter being placed flat, simply to act as covers.

It will be noted also, that straps have been used between the interlocking and Spanish tiles, and between the Spanish tiles and the trimmings. These straps furnish a better foundation to start upon in changing the setting from one style of tiles to another, and also permit necessary movement between dissimilar surfaces in shrinkage.

SETTING IN SAGGERS.

There yet remains one method of setting that has not been touched upon directly, though the use of rectangular hollow fire-proofing as already described, borders closely upon it.

A sagger is a fire-clay box, or receptacle, made for containing and protecting clay wares in firing. Saggers are naturally of a variety of shapes and sizes, according to the ware they are to contain. They are used most largely in the pottery industry. Nearly all pottery, excepting flower pots and the cheapest grades of stoneware, are saggered. Any other clay ware, which by reason of its light cross-section, is not able to stand the weight in piling to the necessary height in kilns, or which must be protected from flying ashes, dust and soot, or from the burning off of its glaze, or damage to its color by direct impingement of the currents of kiln gases, may be saggered with the same propriety as pottery. Saggers are usually made without lids or covers. Being stacked one above the other in tall piles or "bungs," the bottom of the second forms the cover to the first. At the top of the bung, an empty sagger is usually inverted over the last, as a cover. Sometimes cover slabs are made for the top course.

Only one plant was found in this country which had used the sagger system; viz., the Bennett Roofing Tile Company, of Baltimore, Md. This plant was running in connection with a white ware pottery, and it is not to be wondered at that many of the pottery methods were carried over into the tile plant. Other roofing tile plants in their beginning are known to have used saggers, but none have persisted in it. The great objection to using saggers is the expense. They are quite

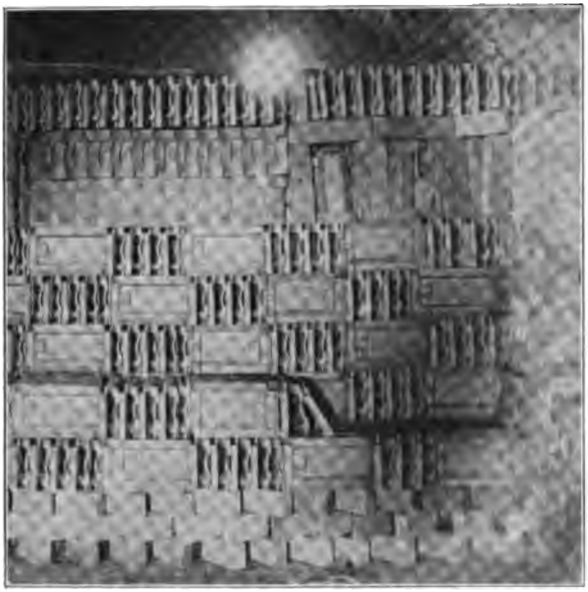


Fig. 169—Setting of Tiles and Terra Cotta, National Roofing Tile Company, Lima, O.

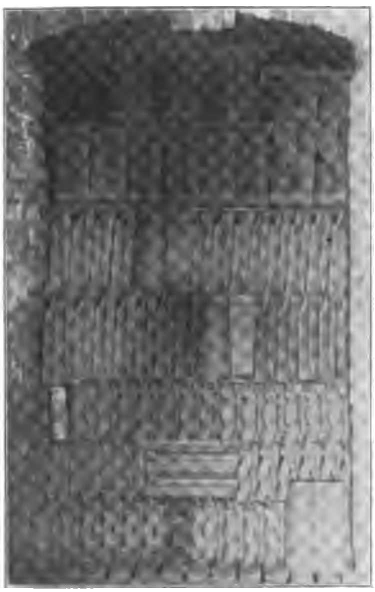


Fig. 170—Doorway Showing Mixed Setting, Mound City Roofing Tile Co., St. Louis, Mo.

expensive to make; their breakage is very heavy; they do not nest close, and hence use up kiln space rapidly, and they weigh a good deal, and hence consume much heat on each burn.

To make them more durable they are usually made in oval or round shapes, rather than square, as would best suit tiles. With the round saggers much space is lost in the kiln, making the capacity of a kiln very small when compared to the regular setting.

While the use of saggers cannot be advocated for the setting of regular roofing tiles, more can be said in their favor for glazed wares and the subject will be taken up in the chapter on glazes.

SUMMARY.

While very little, if any comparison can be made as to economy, between the two principal systems, the class of ware burnt in one case could not be burned by the other method, and in the other case, it would not pay to use kiln blocks for setting ware that is not to be burned hard.

The proper method to use will depend on which kind of ware the manufacturer wishes to make, vitrified or porous. The clay to be used will very frequently govern the details of setting within the general system. Some clays begin to vitrify so early that they could not be burned except in kiln boxes.

As between kiln blocks and saggers, everything is in favor of the kiln blocks. When drawing a kiln, they can be stacked to the sides of the kiln in a comparatively small space, while the saggers are very bulky and most of them must be removed from the kiln, thus making an additional cost of handling and incidentally more breakage also. The kiln blocks are heavy and strong and resist handling well, while saggers are fragile and of short life at best. Both kiln blocks and saggers materially increase the fuel consumption per ton of finished clay ware produced, and the blocks probably weigh more in proportion to the ware they support.

CHAPTER IX.

KILNS FOR BURNING ROOFING TILES.

The burning of clay wares—or baking as it might more properly be called, since the wares themselves do *not* burn—is the last, most difficult and most critical step in the whole process of manufacture. By it, the solid, but still soft and easily destructible dried ware is converted into a hard, more or less vitreous weather-resisting artificial rock. The process is accomplished by bringing the ware through a series of increasing temperatures, affording time at each stage for the chemical reactions to take place, and finally reaching a point, in vitrified wares at least, where the body is in a state of incipient fusion, and ready at the least strain or least increase in temperature to undergo deformation and loss.

The chemical processes concerned in the burning, and the way that the qualities of the product are affected by and dependent on burning conditions, have been set forth somewhat fully under testing, in Chapter III. The present discussion will deal chiefly, therefore, with the apparatus and methods by which this work is accomplished.

Since clay burning has been going on in all parts of the world since the earliest stages of culture, when man had hardly risen above savagery, and since for some hundreds of years at least, this work has been carried on on a large scale, and as one of the prominent and essential industrial arts, it would seem natural to expect that experience would have eliminated the more crude, inefficient, and uneconomical methods and enabled clay workers to limit their selection of kilns to a comparatively few well proved types. To some small extent this has occurred, but there still remains an astonishing variety of kilns, of old and well known types, and not including those newer phases which have not yet had time to fully win their permanent place, and it is not yet possible to prove beyond mere unsupported opinion which are really economical and which are not.

Beyond question, there are many kilns in existence, whose type is unscientific and whose performance is poor, and yet they are not only still used, but new ones are built. The problem of deciding on what is really good and what is not, is much complicated by several factors—

1st.—The inherent variation in clays. Some clays are fired rapidly and some slowly. Some are very sensitive to the least over-firing,

some stand punishment without much effect. Some require very strict cooling conditions, and some may be chilled recklessly.

2nd.—The variety in the products. Every kiln must be suited to its charge. It would hardly be natural to expect to fire gas retorts weighing tons, and table-ware weighing ounces, in one and the same structure. The form, size, cubic capacity, doors, arrangement of fire holes, etc., will all have to be adjusted with reference to the ware habitually fired.

3rd.—The inherent variation in fuels. Furnaces must naturally be adjusted to fuels, wood, soft coal, hard coal, lignite, coke, oil and gas, but in addition, the kiln chamber will require adjustment, according to the flame length of these various fuels. Some fuels will compel the use of a muffle to protect the ware, while with other fuels a muffle kiln will have to be abandoned in favor of an open type, in order to get the heat distributed safely.

4th.—The unwillingness of clay workers to publish and compare data. Trade secrecy in the past has had a strong control of the clay-working arts. And today the feeling still holds to a very surprising extent. Even if clay workers were anxious to eliminate poor methods, and low grade kilns from their factories, there are enough barriers in the way of making comparisons sufficiently exact to thoroughly prove either for or against many fine points in kiln design. But when manufacturers are unwilling to discuss and compare data, for fear of giving each other a fancied advantage, or of exposing their own lack of knowledge, the problem of weeding out inefficiency becomes mountain high.

Without doubt, other causes in explanation of the status quo might be brought forward, but enough has been said to show why burning is still so little of an exact science.

If the countless variations in kilns which have been or are in existence are studied, and indeed it is rare to find two alike except on the same plant, it will be found that these variations are classifiable to a considerable extent, and that the classes thus made will include large numbers of kilns varying in small or immaterial details, while agreeing in fundamental principles. Such a classification recognizes two main subdivisions, I, periodic or intermittent kilns, II, continuous kilns.

The names indicate the nature of the distinctions. In intermittent kilns a charge of ware is fired to the finishing point, cooled down, discharged, the kilns are reloaded and the same cycle is repeated. In continuous kilns, by movement of either the ware to the fire or the fire to the ware, masses of ware are always being brought to their finishing point, and hence in other parts of the structure, ware is being heated up and cooled down, so that all parts of the burning cycle are going on at once in different portions of the continuous kiln, while in the periodic kiln one thing at a time is done, and so far as possible, the same thing in all parts at once.

PERIODIC OR INTERMITTENT KILNS.

This group is the numerous and commonly represented one. A very large percentage of all ceramic kilns belong in this group. Though admittedly a less scientific and perfect apparatus from the fuel combustion standpoint, they have certain virtues which will always guarantee their use. They are cheap to construct, and therefore require less capital to begin operations. They are rapid and independent of each other. They produce just as good, and in some kinds of ware better products than the continuous.

The intermittent kiln is almost the sole resource in the roofing tile industry of America. In Europe, the situation is reversed, or at least, continuous kilns are vastly more common than here. Intermittent kilns, as found in use in roofing tile plants in the United States, may be classified as follows:

- Intermittent or Periodic Kilns
  - Round
    - Chimney Draft......
      - Single stack
        - Interior (a)
        - Exterior (b
      - Multiple stacks Exterior(c)
    - Mechanical Draft (d)
  - Rectangular
    - Chimney Draft......
      - Single stacks (e)
      - Multiple stacks (f)
    - Mechanical Draft (g)

There are numerous other types of intermittent kilns, but as none of them are now used in roofing tile plants, or seem to be in any sense an improvement of the kilns now in use, no effort will be made to make this classification more comprehensive.

ROUND KILNS.

A. Round Down Drafts with Interior Stacks.—While there are some very good features in this type, it has been but very little used in this industry. One firm, the United States Roofing Tile Company, is the only one in the United States using it, although it has been quite extensively used in other branches of ceramic manufacture.

A clear conception of this kiln, as used by the above company, can be obtained by reference to the drawings shown on page 391 (Figure 171).

The kiln as built is twenty-four feet inside diameter. The walls consist of a nine-inch fire brick lining, and a thirteen-inch outside wall of common brick. From the floor to the spring of the arch, is seven feet six inches. The crown has a rise of five feet three inches, thus making the total inside height from the floor to the apex of crown, twelve feet and nine inches.

The foundation walls are four feet wide by three feet deep, measuring from the grade line. The "hub," as that portion of the kiln in which the furnaces are constructed is called, is thirty-six inches wide.

By referring to the sections showing the ground plan, the flue system of the kiln can be readily understood. It will be seen that below all other parts of the floor is the large four-way or cross flue; this flue is twenty-four inches wide by thirty inches deep. At the junction of the four-arms, and carried by the side walls to the large flue, is the center stack, which is twenty-four inches in diameter, with four inch walls of circle bricks.

Connecting the four outer ends of the four-way flue is a circular or ring flue, twelve by twelve inches, shown in section D-D. This ring flue intersects the main cross flue, so that their upper surfaces are on the same level. On top of the ring flue is a system of radial flues shown in sections E-E and F-F. The radial flues are sixteen in number, nine by nine inches in cross section, consisting of eight long flues reaching from the stack to the side walls and eight short or intermediate flues that reach from the ring flue back almost to each bag.

The covering to the radial flues is of stock floor or flue bricks, twelve inches long, part of them having an open slot one by five inches on one side. (See Section FF.)

The space between the radial flues is filled in solid and paved level with the top of the bricks covering the flues. Thus the kiln has a solid floor over about one-sixth of its area. The flue bricks can be taken out at any time in order to clean out the flues; no other part of the floor need be disturbed. The slotted bricks can be shifted about to secure the best distribution of the gas currents.

It will be observed that the bag walls, G, are very low in this kiln. only about two feet above the floor. It has been found by experience that a higher bag throws too much heat to the top of the kiln. With the present bag the heat equalizes very nicely. The firing is done with natural gas.

The small sketch shows the style of furnace used. A two-inch gas line is carried around the kiln on the hub. At each furnace a one-inch drop line is carried down to a point where the blast from the burners will strike just above the floor level. There are two stop-cocks in the drop line, one in the down pipe and the other between the burners, thus one burner can be lighted at a time. The burners are of the ordinary type, having a cast iron mixer, into which short lengths of two-inch pipe are put to form the burner nozzle.

Just above the burner can be seen two openings, five by six inches. When the kiln is first lighted these openings are closed, but as the burn progresses they are opened more and more until wide open at the finish.

The heat generated in the bags passes up into the kiln, is drawn down through the ware into the radial flues, then into the ring-flues, which in turn carry it to the four-way cross-flue, and thence it passes up the stack and out to the open air.

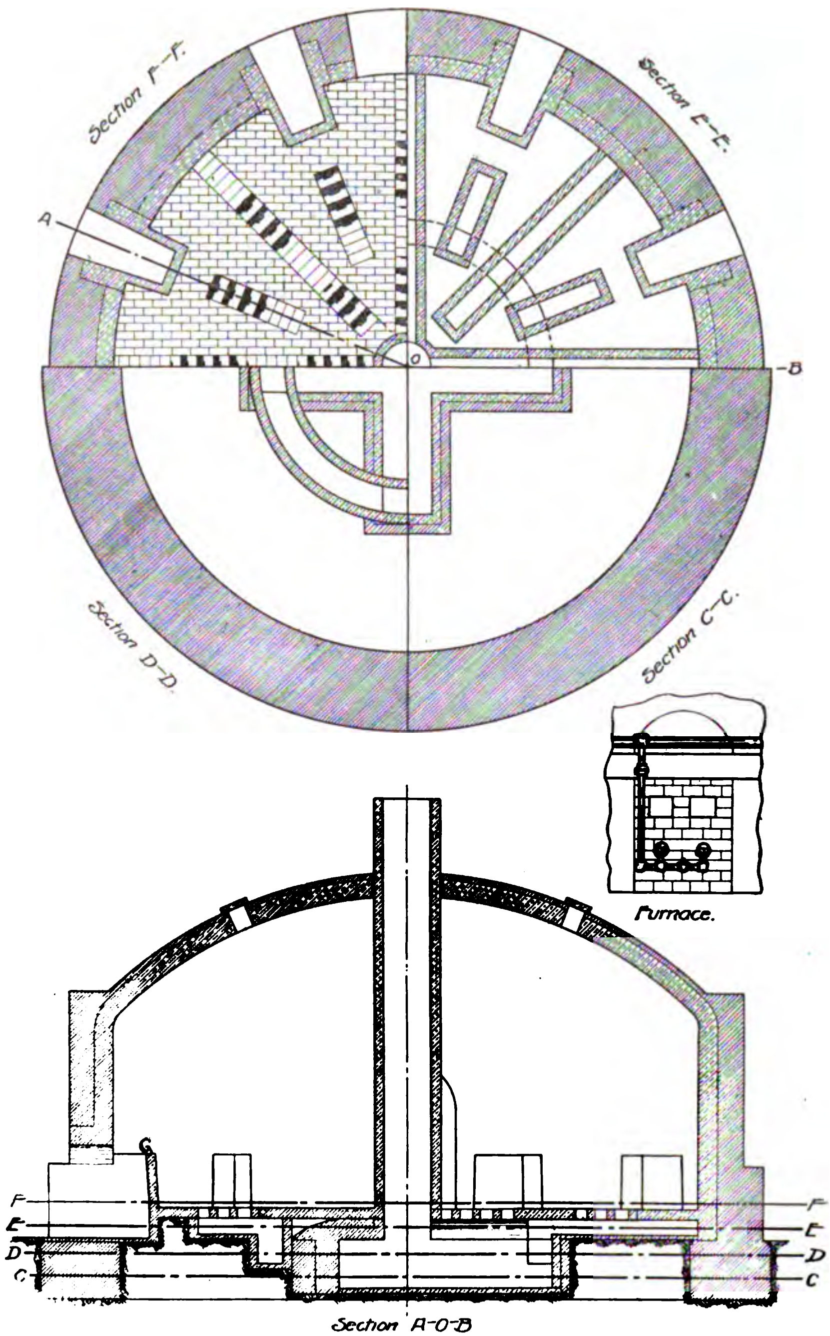


Fig. 171—Center Stack Down Draft Kiln, United States Roofing Tile Company, Parkersburg, W. Va.

In an ordinary burn, lasting from four to five days, about 400,000 cubic feet of gas are consumed.

Advantages of this Kiln.—First: The flue system lends itself very easily to changes found necessary from burn to burn to regulate the distribution of the draft. *Second*: The flue system can be very easily cleaned. All that is necessary to do is to lift out the flue brick, and then with a small fire shovel remove the debris. *Third*: The center stack becomes heated very early in the burn, thereby furnishing a good draft at a time when it is needed to remove the water smoke and prevent the deposition of scum or whitewash. *Fourth*: The fact that all waste heat must pass through the center of the kiln insures that the center will not be materially lower in temperature than other parts. *Fifth*: In comparison with kilns having their stacks outside, it is very much cheaper to build. The center stack is only four inches thick and is very short. There are no underground flues to connect it with the kiln, as in outside stacks.

Disadvantages.—First: The available kiln space is reduced by about twice the cubic contents of the stack each burn. This, however, is not large, rarely over five per cent., and often less. *Second*: The strongest objection is due to the stack being in the way of setting and drawing the kiln. This objection is valid, especially with roofing tiles set in kiln blocks. It becomes very troublesome to work around the stack. Also, the dry ware to be set can only be brought half way in the kiln on a car. With trucks this trouble disappears. If the kiln were built larger it would be possible to get a car of tiles past the stack, but with small kilns it is not.

While the stacks as built by this company have no dampers on them, this type of kiln admits of very easy control by a top damper. It is a much more economical plan to have a damper fitted to the top of each stack than in any other way, and the draft can be kept under control as the heat increases.

B. Round Down Draft Kilns with Exterior Single Stacks.—There are three plants using kilns of this type. One that has been in use for the past ten or twelve years in the plant of the Cincinnati Roofing Tile Company, using coal for the fuel, is shown in the drawing, Figure 172.

The kiln is twenty-two feet in inside diameter, with walls twenty-two inches thick above the hub. The hub has two offsets. The inside height is seven feet to the spring of the crown, with a five foot rise, making twelve feet high at the apex. The bags in this kiln extend up five feet above the floor, differing from the gas-fired kiln previously described. It was found better here to carry the gases from the coal furnaces up into the crown of the kiln, and allow combustion to complete itself at that point and then pass down through the ware. The quality of the fuel is therefore the determining factor in this change.

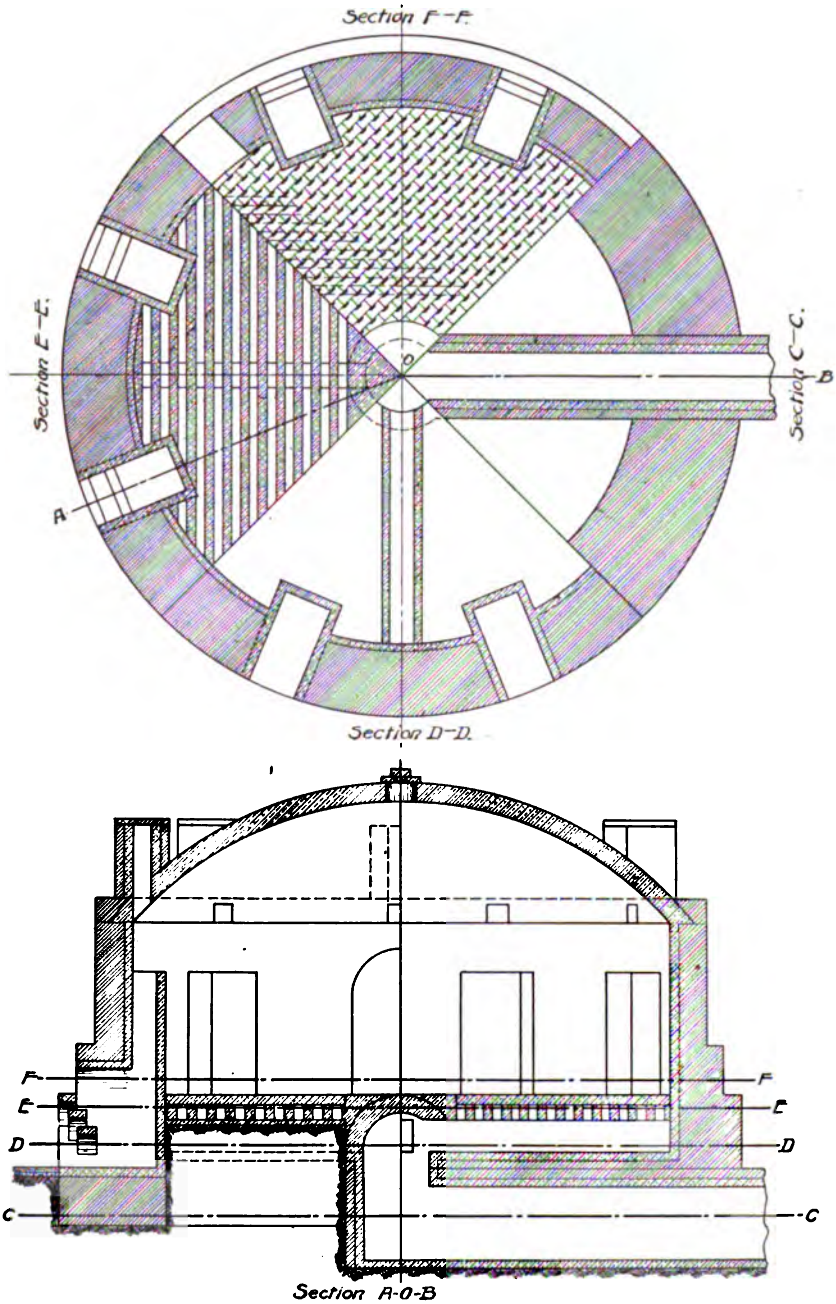


Fig. 172—Round Down Draft Kiln. Cincinnati Roofing Tile & Terra Cotta Co., Cincinnati, O.

The flue system is in part like the kiln just described. In the center of the kiln, and under the floor level, is a well-hole thirty inches in diameter. Leading from the well-hole out under the wall of the kiln to a stack is a large flue, twenty-four by thirty inches. Opening into the top of the well-hole are four cross-flues, twelve by sixteen inches, in cross-section, which lead to the walls of the kiln. Just above, and crossing the four flues at right angles in each quarter of the kiln, are a set of small, narrow flues four by twelve inches. (See Section EE.) Above these narrow flues is another set of cross-flues upon which the open floor bricks, shown in FF, are placed.

The heat, in passing through the kiln, enters the bags, is carried well up into the crown, passes down through the ware, sieves through the floor bricks into the first small flues, then into the lower ones, and is thence conveyed to the four cross-flues, which carry it to the center well hole. From here it passes by the large flue out to the stack. A vertical damper is placed between the kiln and the stack. In the sections marked FF, the floor bricks should be shown in parallel rows, and not staggered, as indicated.

A rather peculiar feature of this kiln, not seen on any other, is the small vent stacks over each furnace bag. These stacks are about three feet high, and nine by nine inches in cross-section. During the most of the burn they are kept covered with slabs, but in the early part or warming-up period they are more or less open, allowing much of the smoke from the coal fuel to pass out. This gain is at the expense of much of the heat which the coal has generated. The idea is not worthy of imitation.

The furnaces of this kiln are also unique, in that step-grates of brick arches are used. No iron grates are employed. The arches are each about five inches lower than the one above, and sit back into the furnace about five inches farther. In firing a furnace of this type, the fire is lit on the floor, under the bottom arch and well back into the bag. As the fire increases, fuel is fed in from above the uppermost arch. Instead of raking out the ashes, they are allowed to fill up, until at last the fuel fills the fire hole completely, drawing its supply of air through the spaces between the arches. The furnace is like an ordinary dead-bottom one, but the arches act as a substitute for the mass of clinker which holds up the fire and lets air get through it. The brick arches, or step-grates, are widely used abroad, but are uncommon in the United States. For some coals, they offer great advantages over the clinker grate. The only disadvantage they offer is in cleaning out the fire hole, either during or after the burn. With a very clinkering coal, this trouble might be rather serious, but with ordinary fuel, it would be unimportant.

This company uses these fire-holes as miniature gas producers. That is, they generate the gas in the fire-box, and complete the com-

Fig. 173—Gas Producer Furnace Under High Fire, Cincinnati Roofing Tile & Terra Cotta Co., Cincinnati, O.

Fig. 174—Double Furnace Down Draft Kiln, Ludowici-Celadon Co., New Lexington, Ohio.

bustion in the kiln. It will be seen in Figure 173 that the entire lower part of the furnace has been shut up with bricks and kiln blocks. The fuel is piled up until it nearly shuts off the air space under the arch. As the fuel roasts and cokes, it gives off gas which passes up the bag; meeting a supply of air at the inlet-pipe shown above the furnace, the two mix and pass on into the kiln, burning as they go. Complete combustion does not take place until the gases have traveled a considerable distance.

Advantages.—First. The entire flue-system, except the stack-flue, is above grade, thus insuring a dry bottom to the kiln. *Second.* The furnaces are cheaply constructed.

Through long experience with this kiln, it has become possible to obtain very uniform burns, with but a small percentage of loss.

Disadvantages.—First. The flue system is rather expensive to construct. *Second.* The flues are very hard to clean. It is necessary to take up the upper set in order to reach the lower ones. *Third.* The draft is very apt to be stronger over the four cross-flues than elsewhere. No provision has been made to prevent this. *Fourth.* There is no provision made to control or shift the hot gases to various parts of the kiln, other than the manipulation of the fires. *Fifth.* The small stacks are an added expense, and when opened only serve to carry the heat from the bag direct into the air. It would be better not to generate the heat in the first place, if it has to be gotten rid of. *Sixth.* The furnaces are very hard to keep in repair. The small arches are very easily knocked out, while cleaning out ashes and clinkers.

As to the method of firing; viz., working the furnace as a gas producer, if properly handled, it is a very good plan. It puts the combustion of the fuel and the evolution of the heat at a point where needed, and where the greatest benefit can be derived. Another strong point in its favor is that very little ash or dust is carried over into the kiln. The air in passing through the thick fuel-bed creates an intense local temperature, which makes the ashes sticky and there is little tendency for the ash to fly along into the kiln as in flat-grate furnaces. It takes about five days, using the best Pocahontas coal, to fire off a kiln. Depending on the climatic conditions and the kind of ware set, the amount of fuel consumed runs from fifteen to twenty tons per burn. A comparison of fuels used in various plants is of little value, unless all conditions are considered.

The Ludowici-Celadon Company, at its New Lexington, Ohio, plant, uses kilns twenty-six and thirty feet in diameter, and about twelve feet high in the center of the crown inside. Their main difference from the preceding is the construction of the flue system, which is in reality a combination of the two previously described. The gases are all collected in a center well-hole, and sent to the stack by a flue leading out under the kiln wall. Leading into the well-hole are

radial flues, which reach out to the outside wall between the bags. About midway between the well-hole and the wall is a ring flue, intersecting all of the radial flues. From the ring flue, shorter radial flues are led off between long ones, and terminating at the point of the bags. Thus the kiln bottom is well served with radial flues. On top of the radial flues is a zone about eighteen inches high, traversed by parallel cross-walls, supporting the paving course or floor proper. These walls are built with spaces between each brick, as open as consistent with stability. The common name for this is "feather work" or "mid-feathers." The purpose of the "mid-feathers" is to permit the gases which have passed the floor to flow laterally in any direction to the point of escape with the least resistance. The clogging of one avenue leaves many others available in kilns in which this mid-feather construction is used. The mid-feather, however, is not a mode of forcing the gases to flow to definite points or to insure distribution in passing through the floor. It has no such function, but in many kilns it has been used as if it had. With no means of controlling the distribution of the draft except the "checker-bottom" and "mid-feathers," the worst sort of distribution is likely to result.

There were two sets of furnaces on these kilns, one set using coal and the other natural gas. The kilns were heated up with coal and finished off with gas; the reason being that gas was more expensive than coal. The gas, being less apt to flash the ware than coal, was used to finish the burn, rather than start it.

It will be observed (Figure 174) that there is a large three-inch gas line around the kiln. From this line, one-inch lines pass down to the furnaces, which have been built in between the regular coal furnaces, which are shown closed up with kiln blocks. Since the above notes were taken, the company has been enabled to obtain a greater supply of gas, and has discontinued the use of coal.

Advantages.—First. The flue system is largely above ground, insuring dry bottoms. *Second.* The radial flue system, covered by mid-feathers, allows the heat to move freely under the floor, and thus to equalize. *Third.* The floor or flue bricks, being easily movable, enable the draft openings to be rearranged, by inserting solid bricks in place of perforated ones. They also facilitate the work of cleaning the bottoms.

Disadvantages.—It has a weak draft in the early part of the burn. This is typical of all kilns having deep bottoms and outside stack connections. They also are subject to weather changes. As a whole, it can be said that these were the best round kilns found in use.

One other plant was visited in which round kilns with outside stacks were used. The kilns in this instance were of twenty-six feet inside diameter, and of the usual height. The exact arrangement of flue system in the bottom could not be obtained. It was much too

deep-seated; that is, the floor was at grade-line and the flue system was all below grade, and certainly would be likely to be very damp. The tiles that were being produced in this plant had all the indications that such was the case, for they were not only soft burned in the lower part of the kiln, but were very badly scummed.

C. Round Kilns with Multiple Self-contained Stacks.—There was only one plant using this style of kiln. In this instance, the kilns were of two sizes, twenty-four feet and twenty-eight feet in diameter inside, and having a central inside height of about twelve feet. The bags were about thirty inches high above the floor. The floor itself was nearly solid, except for openings five inches by five inches, about twenty-four inches apart, along radial lines from the center of the kiln to the walls. These openings led into flues running from the base of small stacks, located in the kiln-wall between each fire place, toward the center of the kiln. These flues did not meet in the center, or elsewhere. They were about twelve inches by twelve inches, inside dimensions. The stacks were carried independently above the side walls of the kiln about six or eight feet.

In theory, the multiple stack appears good, but the actual operation is otherwise. The idea is that each stack will drain one section of the kiln floor, and that by regulation part of the floor can be brought up or held back at the will of the operator by merely using a damper.

In practice it is found that in order to drive the heat to any one or two sections of the kiln it would be necessary to shut all the other sections off, and in doing so the draft would not be sufficient to maintain oxidizing conditions.

The building of the stacks in the wall of the kiln is a source of weakness to the walls. The stacks become hotter than the adjoining parts of the wall, and hence expand more, bringing about a continual strain, which in time will rack and materially weaken them.

The above described multiple-stack kilns are using natural gas. The burners are of a patented type, known as the Kearns Automatic Gas Burner. The burning is of three to four days' duration, and consumes from 140,000 to 160,000 cubic feet of gas.

Advantages.—*First.* It is claimed that the draft can be localized to any particular part of the kiln. *Second.* No yard room is taken up by the stacks. *Third.* They are cheaper to construct than outside stacks, being shorter. *Fourth.* The kiln has no deep flue system, as the stack openings may be on a level with the floor if desired.

Disadvantages.—*First.* The draft control is not nearly as exact or satisfactory as the projector of the idea expected, as explained above. *Second.* In starting off the burn, the stack areas are in excess of the kiln needs, and reversion of the draft is very common; i. e., a stack will suck cold air into the kiln instead of carrying hot gases out. This is difficult to prevent, and takes a great amount of care and watching.

D. Round Kilns with Mechanical Draft.—At no point were kilns of this variety being used, but this system could very well be applied to many of the round kilns now in use, which now have a sluggish draft and are giving poor results at high fuel cost. The system will be discussed in connection with rectangular kilns.

Summary on Round Kilns.—It can safely be said that the use of the round kiln in the roofing tile industry has passed its climax, and is rapidly being replaced by the rectangular kiln.

While the round kiln can be built cheaper, and has a longer life, it has drawbacks that more than outweigh these advantages. The great objection for roofing tile purposes is that they interfere so seriously with convenience in setting. The curved walls do not lend themselves readily to the system of setting necessary. It is impossible to brace the stands at the side walls in the proper manner. Too much valuable space is lost by having to insert so many side braces in the tile benches. Also, the individual fire-bags or "pockets" around which the ware has to be built interfere seriously. A circular flash wall is possible and is undoubtedly better, but is seldom used, on account of difficulty in keeping it up.

A much greater per cent. of flashed ware is obtained in round kilns than in the rectangular. This is due to the fact that about one-half of the fire-bags are throwing their hot gases into the kiln at right angles to the benches, that is, against the sides of the tiles, while in the rectangular kiln all hot gases come into the kiln parallel with the benches.

It cannot be denied that excellent results can be obtained with the round kiln. It has an unquestionable advantage in the ease with which a flue system can be made to give even draft over the whole floor.

Fuel consumption is less in the round kiln than in a rectangular kiln of the same superficial floor area, owing to a proportionately less wall area. This difference is probably offset by the less lost space in the rectangular kiln, by which the heat that is generated is made to do more work.

But notwithstanding all the good qualities of the round kiln, it is on the average impossible to turn out ware as cheaply as in the square kiln, or of as good quality and quantity.

If built at all for burning roofing tiles, the round kiln should be large, about thirty feet in diameter, so that the loss in setting will be reduced to a small factor. The height of the kiln should also be greatly reduced from that in general use at the present time (twelve feet). It would be better to build eight feet, and at the outside figure nine feet in height at the center of the crown. The kilns built in the past are so high that it is extremely hard to get the heat to the bottom.

Very frequently the top ware is overfired in the effort to bring up the bottom temperature. With a lower crown this would be largely overcome.

As to the flue system, it should be of the radial type, leading to a central well-hole. The floor should be as near solid as possible, on account of the large amount of scrap that will otherwise fill up the flues. The so-called checker floor is not recommended.

The chimney, if one is used, should be outside of the kiln. One large stack for four kilns is satisfactory. Mechanical draft should be used where possible.

The furnaces of course will depend on the nature of the fuel. If coal, either the flat or inclined grate-bar type is preferred. While the flat grate-bar furnace will require more labor and attention, it will, if properly attended to, give the best results, and use the least fuel. The main trouble with the flat grate-bar furnace is, that the bed of fuel, if kept thin, burns through in patches every few moments, thus allowing streams of cold air to enter the kiln. If the fuel layer is not kept thin, all the advantages which belong to the flat grate type are lost, and one might as well use the inclined or dead bottom types at once. The inclined grate-bar furnace, on the other hand, is more likely to prove better in the hands of a careless burner, because the fuel layer will slide down the bars, and automatically prevent leakages of air to a large extent, and thus does not require such constant attention.

RECTANGULAR KILNS.

This style of kilns is at the present time most popular among the roofing tile manufacturers, and is likely to remain so. There are at present over half of the plants using rectangular kilns; those rebuilding or putting in new kilns at the present time are all installing the rectangular kilns. This tends to show where the general opinion rests, and it has not come from the desire to try something new, but as the result of actual experience with both types of kilns in many different plants.

The general objections to rectangular kilns are: First, that they are more expensive to build and keep in repair than the round kilns; second, that it is more difficult to get an even distribution of the draft over all parts of the kiln, the ends and corners of the kiln being the most difficult to bring up uniform with the rest. Both of these objections are real, but are overbalanced by the advantages.

E. Rectangular Kilns with Single Exterior Stacks.—Two plants were visited in which kilns of this type were in use. The kilns themselves were very closely like that of the Detroit Roofing Tile Company, which differ only in the use of mechanical or fan draft instead of a stack, and the description and drawings will be given under that heading (G.).

The points in favor of a single stack vs. multiple stacks are much less pronounced in rectangular kilns than in round ones. If rectangular kilns were square, it would probably be better to use one stack per kiln, as in round kilns, and for the same reasons. But as nearly all rectangular kilns are not square, but much lengthened on one axis (in one instance three hundred feet long by only eighteen feet wide), the problem of securing uniform draft distribution over the whole floor surface is much altered.

In general, the advantages which accrue to one stack for a circular or a square kiln can be retained in long rectangular kilns by making the kiln's length equal to two, three or more times the width, and dividing the floor by cross walls into squares, each of which has a stack and a complete flue system of its own. For instance, with a kiln eighteen feet wide the length might be made thirty-six feet, and two stacks used, or fifty-four feet and three stacks, or seventy-two feet and four stacks, etc. The kiln thus becomes in effect a series of contiguous square kilns in line, surrounded by exterior walls and roof in common. The general principles found useful in round kilns obtain with rectangular kilns, also, viz., floors above grade level, shallow flue systems to avoid dampness and excessive fuel consumption, exterior stacks to save loss of interior space, a flue system extending to all parts of the floor with equal frictional surface, solid floors covering the flue system, perforated to admit the gases so as to give to every square yard of floor area an equal draft, a stack adequate to give a good draft in the beginning of the burn, when the temperature is low, and damper arrangements which will give entire control of the draft at any stage.

F. Rectangular Kilns with Multiple Stacks.—By this is meant the use of stacks in more frequent proportion than one per "unit square of floor space" (i. e., a length of space equal to the width of the floor). Multiple stack kilns use from two to five times as many stacks as are recommended in the "unit floor space" plan.

The Eudaly Type.—The type of the multiple stack kiln is the Eudaly, originally introduced as a patented kiln, and sold extensively over the country on the yard-right plan. For years the essential features have been pirated in so many ways that many kilns can now be found which are Eudaly in type, but not in details, and built without authority from the owner of the original patents. This even took place while the original patents were still comparatively new.

A kiln of the Eudaly type is in use at the Huntington Roofing Tile Company's plant, Huntington, W. Va. It is eighteen feet wide by thirty-eight feet long inside, by seven feet to the spring of the crown. The crown has a rise of five feet, making the total height twelve feet. The floor system is the characteristic feature. The rectangular bottom is divided by a center wall extending lengthwise of the kiln bottom from

end to end. At right angles to this dividing wall are cross walls, spaced opposite each furnace, and extending from the kiln wall to and connecting with the center wall. Thus the kiln bottom is divided up into sections, each of which has its own flue system, connecting with its own chimney in the side of the kiln wall, midway between each furnace. These blocks are usually about seven or eight feet wide by eight to ten feet long. The area of the stack draining this area is small, about twelve by eighteen inches.

These stacks connect with flues running straight through the middle of each section to the center wall. The bottom of the stack and the flue are on the same level, generally about thirty-six inches below the floor line. The flue is about eighteen inches deep. The whole section, seven feet wide by eight feet long, is now covered with small four-inch mid-feather walls parallel to the axis of the kiln and five inches apart. These mid-feather walls cross the flue in the center by arching, or by tiles on edge, or even lapping each course till one brick will bridge the gap. The mid-feather walls are now covered with perforated floor brick. This makes a floor through which the gases pass with perfect freedom at any place, and therein lies the vital defect of the system.

The claims made for the Eudaly kiln were that by having each section of the floor drained by a stack of its own, perfect control of the draft was assured, it being only necessary to operate the dampers on the stacks to force the draft to any particular section of the kiln. This idea appears plausible, but in actual practice it does not work out as expected. The hot gases, being able to pass the floor at any point, will take the shortest road to the stack. The central area of the kiln, furthest from the stacks, and the floor along the cross-walls are practically without draft. There is another trouble, viz., the stack area is extravagantly great. The result of this great stack area and the open or "checker" floor is that the gases supplied to the kilns by the fire boxes rush to the base of the stacks by the "short cut," and leave the more distant parts of each floor section stagnant.

Closing a damper on one stack does no good. Unless practically two-thirds or three-fourths of the dampers are closed, no compulsion is exerted on the draft movement, for the excess of stack area is so great. The cross-walls in the bottom are absolutely ineffective as a mode of control of the draft distribution. There are also too many dampers to regulate. Too much of the burner's time will be consumed for the results obtained.

Ordinarily the Eudaly kiln is fired with coal, but in this instance gas is used. The time of firing is extremely slow, about twelve to fifteen days being spent for the entire burn. It must be remembered that the Huntington Company is manufacturing flat shingle tiles exclusively, and this style of ware and the method of setting at this plant require a long, slow burn to get proper results.

A bad feature of this kiln, as constructed in the above plant, is the height. It is from three to four feet too high. The top area becomes excessively hot and by its radiations down onto the ware there is constant danger of spoiling the top courses. With a low crown filled full of ware, the gases would flow among the ware and heat it much more evenly.

Stewart Kiln.—The National Roofing Tile Company were using Stewart kilns, the inside dimensions of which are fourteen feet wide by twenty-five feet long. They are six and one-half feet high to the spring of the arch, with a three foot rise, giving a kiln of nine and one-half feet in total height, which seems an excellent proportion. Their novel feature is the method of bringing the heat into the kiln, and out again.

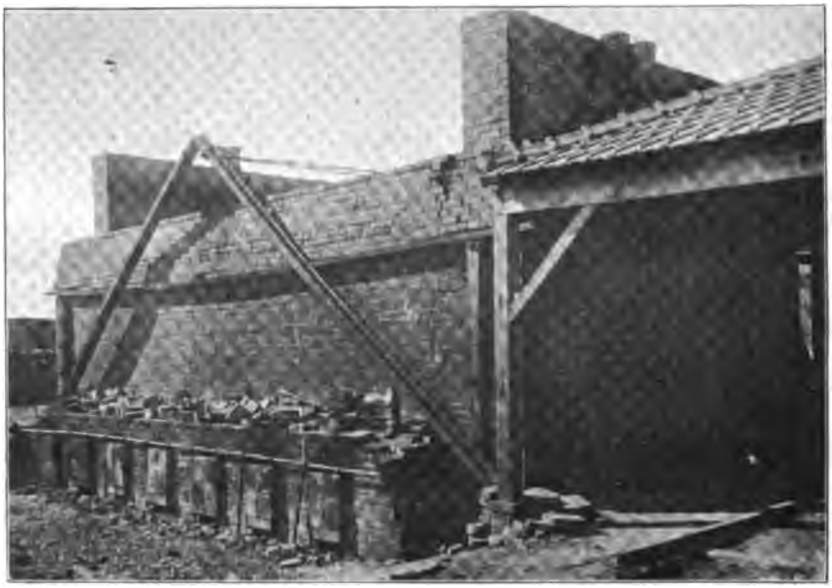


Fig. 175—Stewart Kiln, National Roofing Tile Co., Lima, O.

Along each side of the kiln are flat-grate furnaces, of which the flues lead under the kiln floor to the opposite side, where they deliver the gases up into ordinary fire bags. The furnaces on the right hand side of the kiln furnish the heat for bags on the left hand side, and vice versa. These flues passing under the floor become intensely heated, and transmit a great deal of heat upwards by conduction through the floor, and radiate it among the wares piled above. The gases entering the kiln at the tops of the bags heat the ware from the top downwards. The zone of least temperature is between these two sources of heat, usually about one-fourth of the way between the floor and the top of the setting.

The construction of the flues and the floors requires more care than usual, because they carry the greatest weight and the highest tempera-

ture. Any softening or failure means great loss. The thickness of the floor varies from nine to four and one-half inches in different cases, depending on the wares to be fired. The less sensitive the ware, the thinner the floor may be made.

The gases are then taken out of the kiln at the floor level by stacks opening into the kiln walls. No floor system of any sort for regulating the distribution of the draft is used. This is the weakest point in the Stewart kiln, and has been much improved at the plant of the Columbus Brick and Terra Cotta Company, Union Furnace, Ohio, by bringing in a flue system which is not a part of the Stewart system.

Advantages—First, the main claim for this kiln by its makers is that it is possible to burn the bottom as hard as the top; second, that the bottom of the kiln warms up first so that the ware in the lower half of the kiln does not sweat in the early part of the burn and become kiln marked or scummed by dampness; third, the solid floor makes cleaning very easy and the draft is always unobstructed.

Disadvantages—First, the distribution of draft is very poor. Instead of passing down through the ware to the floor at all points in the kiln equally, it tends to pass over the top of the ware, and down near the end where the outlet flues are located. Thus a large part of the central area of the kiln must be heated by conduction and secondary convection, and not by direct flow of hot gases; second, the loss of heat due to radiation downward into the ground from the flues under the floor is not to be overlooked; third, where necessary to reach a high temperature in the ware, it will be found that the throat to the underground flues will burn out, owing to the heavy fire that must be maintained in the furnaces, in order to carry it under the floor and up the opposite side. This kiln as a whole cannot be recommended, unless its flue system for discharge of gases be materially altered. Even then its fuel consumption is probably pretty high per ton of ware.

Grath Solid Bottom Kilns.—This kiln was found in use at the Western Roofing Tile Company, Coffeyville, Kan. It is fourteen and one-half feet wide by forty-two feet long and nine feet high inside. It has eight gas fired furnaces on each side.

The main difference between this kiln and the one last described is, that part of the heat is carried through under the floor and a part of it can be taken up direct into a bag on the same side where generated. In this respect the kiln is superior to the Stewart, because the furnaces do not have to be forced so hard to get the temperature in the kiln. The amount of heat that need be taken up direct, and not passed under the floor, is regulated by a sliding damper at each furnace.

After the hot gases have entered the kiln, either by one route or another, they are supposed to travel down through the ware and along the floor to the end walls, where they enter openings leading to two

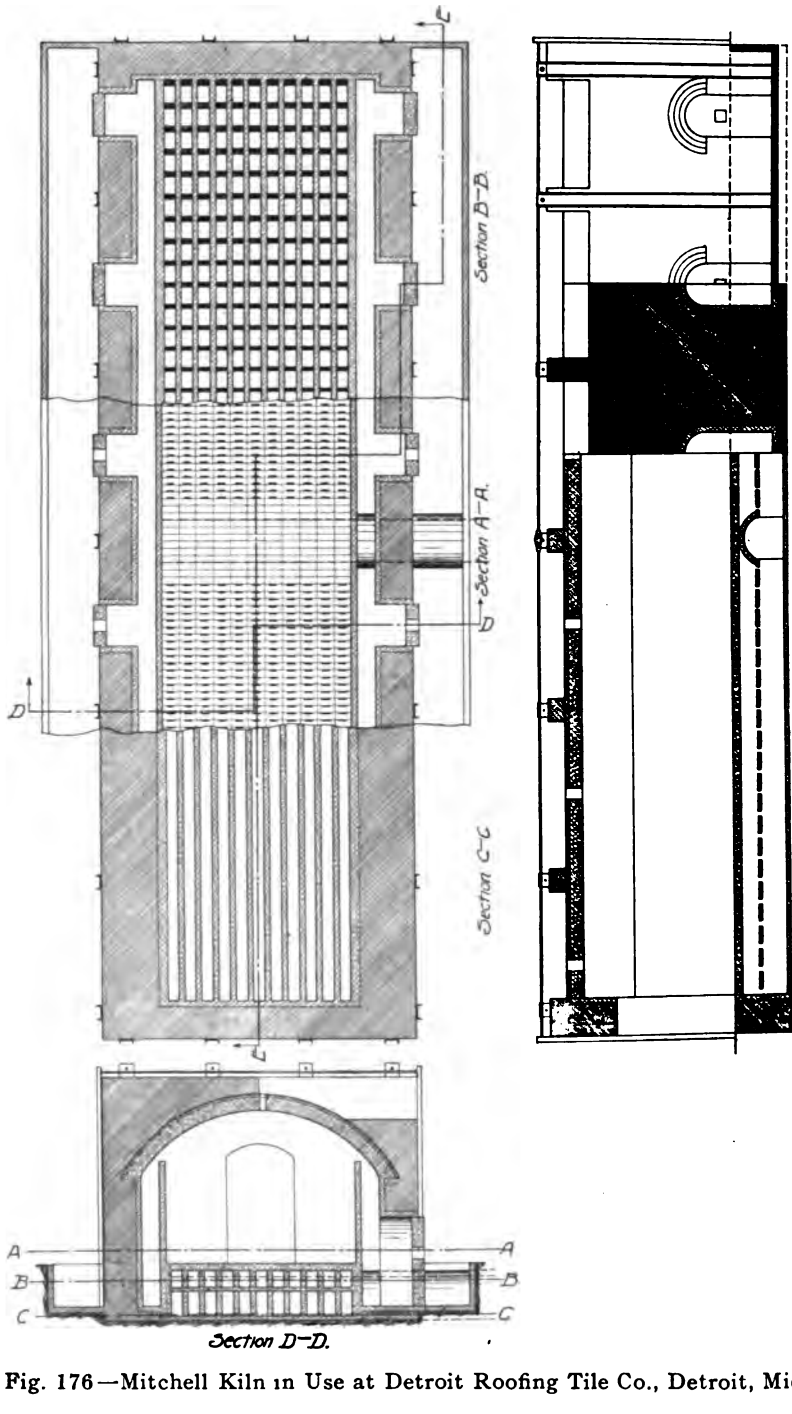


Fig. 176—Mitchell Kiln in Use at Detroit Roofing Tile Co., Detroit, Mich.

small stacks at either end of the kiln. The same objections hold here as for the Stewart kiln, namely, too much radiation loss from the under floor flues, and a very poor draft distribution.

Hence, for economical reasons and uniformity of burns, this kiln is not to be recommended, though it should be given preference over the one last described. It is susceptible of improvement by use of proper flue systems to collect and carry out the gases.

G. Rectangular Kilns with Mechanical Draft.—The Detroit Roofing Tile Company is operating a kiln in a way which may be instructive to others. The drawings of the kiln are shown on page 405. The kiln is fourteen feet wide by fifty-six feet long inside, with a height of ten feet. The walls are twenty-seven inches thick, including the four inch fire brick lining.

The furnaces are now fired with crude oil, but are made large enough, so that grate bars can be inserted, and resort be made to coal at any time. The bag walls are continuous, extending the entire length of the kiln on either side, so that there are no odd corners in the setting. In this kiln it will be observed from the end section D–D that the bag walls are carried well up to the crown; in fact, a four-inch space is all that is left open. Hence, the greater part of the hot gases are thrown well up into the crown of the kiln, before turning down among the ware. The flue system, however, is the important part of the kiln. It consists, first, of a large flue crosswise of the kiln at the center, leading to the fan, which furnishes mechanical draft. Leading out towards the end of the kiln from the cross flue are smaller flues (see section E–E). These flues are about eight inches by sixteen inches, and are covered with kiln blocks, so spaced apart over each flue that openings about two inches wide are left near the center of the kiln close to the main flue. These openings are made larger and larger until at the ends of the kiln they are from four to five inches wide (see Sections E–E and B–B).

After this sub-floor of blocks has been constructed, the mid-feather flue walls are carried up about twelve inches more (see Section D–D). On the top of these mid-feather walls, are placed the open floor bricks or "checkers" (see Section A–A). Immediately over the main cross-flue, the floor is made solid for about five feet wide (see Sections A–A and E–E).

The idea in having the sub-openings through the floors into the flues made larger near the end walls and closer at the center is to equalize the draft distribution, which is always likely to concentrate at the opening into the main draft flue. In this case, the tendency would be to leave the ends and corners cold, and the center hot, if the floor were not built as described. The fact that the floor bricks are laid dry enable them to be moved or shifted at will, and the draft to be changed by inserting solid bricks in place of perforated bricks at any point in the floor where

the draft may have been too great. After the kiln floor is once properly adjusted to suit the local conditions, it will very rarely need to be changed or moved except to clean out the flues. The flues are easily cleaned out; nearly all of the dirt falls upon the kiln blocks separating the upper and lower flues. Hence all that is necessary is to take up the floor bricks and remove the accumulations of scrap and dust. It is not an expensive kiln to build; while the flue system is rather deep, it is of straight brick work, very little chipping or cutting being necessary.

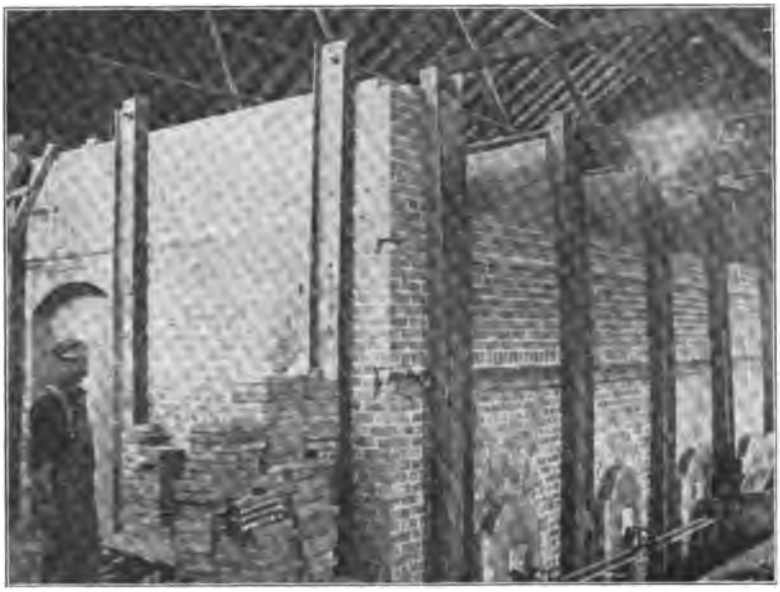


Fig. 177—Outside View of Mitchell Kiln, Detroit Roofing Tile Co., Detroit, Mich.

This kiln as constructed at the above plant is too low in the ground. It will be observed from the drawing that the floor is on a level with the yard grade. The flues are therefore all below grade. In a dry soil this would not be a matter of great importance, but very few localities are so dry that the lower flues are not quite apt to be damp.

In case of coal firing, this question of level of kiln floor to yard level would be very troublesome. It will be noted that the ash pit and furnaces are below grade. Of course, as long as oil or gas is the fuel, this point does not matter.

In Figure 177, the depressed furnaces can be seen, with the oil and steam pipes on the grade line.

The system of staying the kiln is very poor. The large channel irons which serve as buck-staves have been placed on the flat, against the kiln. A channel iron on the flat is very weak. The same amount of iron as has been used in the large channel, if distributed between

two smaller ones placed on edge and using the same tie rods, would support the kiln very much better and the life of the kiln would be greatly prolonged. The proper staying of a rectangular kiln is of vital importance to its durability.

The time of burning this kiln at Detroit is rather remarkable, being about thirty hours from the time of lighting. The temperature is carried to Seger cone 06. Rarely does the time exceed thirty-five hours.

There are several reasons for this very short time of burning: *First*, the clay will stand rapid firing; *second*, the fuel used permits steady firing with no time lost for cleaning fires, the oil being vaporized by steam; *third*, the excellent draft in the kiln, maintained by a fan. The same conditions could no doubt be obtained with natural draft, but it would have to be very strong, and a tall stack would be needed.

Mound City Kiln.—A kiln is being used at the Mound City Roofing Tile Company at St. Louis, which differs from any other in use in the country. It was designed as a continuous kiln, but owing to failure to get satisfactory results from it, its continuous features have been abandoned and the kiln is now used as a compound periodic. It greatly resembles the Dunnachie continuous kiln which was erected in two or three places in this country about twenty years ago, and which also failed as a continuous kiln and was ultimately used as a set of independent units. The Mound City kiln is built in block form, consisting of a double row of chambers four to a row, or eight chambers in all. Each chamber is approximately fifteen feet wide and eighteen feet long. It is fired by four flat grate furnaces, two on either end of each chamber. The two rows of chambers are placed about twenty-five feet apart, so that there is ample room for firing between the rows. Doors are placed at each end of the chambers so that the setting can be done from one side and the drawing from the other.

As originally designed, the heat from a burning chamber was to be carried forward through the next chamber ahead, and then out into the main draft flue. The furnaces are built into the walls as in ordinary down-draft kilns. The heat generated in the furnaces is conducted well up into the chamber by high bag walls. After passing down through the ware, it reaches the floor, which is covered with regular open floor bricks. These floor bricks cover lateral floors extending from end to end of each chamber, and at the center connecting with a larger cross-flue. This latter flue in turn has a "T" connection to the main draft flue leading to the stack or fan. In the case of the Mound City Roofing Tile Company a mechanical draft fan is used.

The kiln to be operated on the continuous plan should be so designed that the heat from the first chamber would pass down through the floor as usual, and then by flues should be carried forward and enter the bags of the second chamber. It would then pass through the ware of chamber 2, and out to the draft fan at once; or, if conditions permitted,

it should be carried through the third chamber as well. Upon reaching the end chamber of one row, the heat should be carried across the intervening space by a connecting flue, and enter the bags of the opposite chamber on the other row.

Advantages.—First. Only a small yard space is required, the chambers being arranged in the most compact form. *Second.* The kiln is cheaper to construct than an equal number of individual kilns on account of saving one wall for each chamber except the first; also, the cost of building a shed over the kiln is greatly reduced, on account of its compactness. *Third.* It can be built in any size to begin with, and then can be extended by the additions of new chambers as occasion demands, without any interference with the original chambers.

This kiln could easily be so arranged that it could either be operated in separate periodic units, or for most of the time as a partially continuous kiln.

For some reasons the continuous kiln proper is more desirable than the above, but for the average roofing tile plant, making a large variety of ware and possibly not operating continuously, the latter is to be preferred. One chamber can be operated at a time, or all at once, to suit the output. With the true continuous kiln the amount of ware set and drawn each day must be very closely regulated. While the fuel consumption in the partially continuous kiln will, of course, be greater than in the regular continuous kilns, this does not offset the conveniences above pointed out. It is so much more economical than ordinary periodic kilns that its use should be attractive in many quarters.

CONTINUOUS KILNS.

In the ordinary periodic kiln the waste of fuel is prodigious. The gases passing out of the kiln are discharged into the atmosphere at a temperature but little below that of the ware itself, and their heat is lost. The kiln, on reaching its finishing point, contains a great quantity of heat stored up in the wares, its walls, roof and floors and fire-places. This, also, is commonly thrown into the atmosphere and wasted. In recent years a part of the waste heat of cooling is often utilized for drying purposes, but under the best conditions there is still a heavy heat loss in cooling.

The continuous kiln in its fundamental form seeks to obviate these two sources of heat loss—first, by using the hot products of combustion through chamber after chamber until they become so cold as to be useless; second, by using the heat of cooling chambers to pre-heat the air currents passing into the kiln, so that the amount of fuel needed to raise the temperature of these currents to the highest temperature required in the burning of the clay wares is only a small amount. No more thoroughly economical device than the continuous kiln for ac-

complishing a thermal reaction on a large scale is to be found in the field of metallurgical or ceramic engineering.

Only one plant in America is using a continuous kiln exclusively for the burning of roofing tile, viz., The Ludowici-Celadon Company, at Chicago Heights, Ill. It has had a continuous kiln for several years. The Alfred Clay Company, Alfred, N. Y., also has a continuous kiln, but is using it more for the burning of pressed bricks than for roofing tiles. The latter are nested in among the bricks when burnt in this kiln.

A true continuous kiln is constructed in ring form, or at least a closed loop of some sort. It may be circular, oval, oblong or square, and even have parallel chambers connected across the adjacent ends to establish the circuit. It may be a continuous tunnel, or a row of compartments separated by cross-walls and connected by flues. The cross section of the tunnel or compartment may be as little as eight feet by ten feet, or as much as twelve feet by forty feet. Where the chamber form is used, the arches may be turned lengthwise or crosswise—the latter is usual. It is necessary to construct very thick buttresses at the end walls or side walls to hold the strain of the arches, or else other means of bracing. Where the kiln is one continuous chamber the arch is continuous with the kiln chamber. In this case it is better to brace the entire side wall of the kiln very strongly with "I" beams and cross tie-rods in order to carry the side thrust.

The kiln at Chicago Heights is a considerably modified Hoffman kiln. The firing is done entirely from the top of the kiln, through small fuel holes spaced equally over the top of the chamber, about four feet apart. Directly under each of these fuel holes it is usual to build a kind of chimney of checker brick work, from bottom to top, so that the fuel, which in these instances is fine coal, when fed into the firing hole, rattles down through the checker work, lodging as it goes and burning where it lodges.

In these kilns the tunnel is not cut up into lengths by cross-walls, or even dropped arches in the roof to mark off the length of the chambers. Hence it is usual to consider the distance from door to door as a chamber. The doors usually open through the kiln walls at about twenty foot intervals.

It is usual in operating a kiln of this kind to set one or two chambers each day. At the end of each chamber it is necessary to form some sort of draft regulator. For this purpose a temporary partition is made of light strips of wood, upon which a cheap and rather heavy paper is fastened in place, often daubing the joints with soft clay. This partition must close the entire cross-section of the kiln. When the paper partition is in place, the setting begins again until the proper distance is reached for a second paper partition, which is then put up, and thus the setting goes on.

In the side wall or floor of the kilns, short connecting flues open into the principal duct leading to the stack, or fan when one is used. This duct may be below the floor, or in either side wall, or even in the roof of the kiln, but the commonest construction is to make the main tunnel in two parallel sections, connected across the ends by smaller flues, and arranging the draft duct between the two tunnels, so that connection with it can be made freely from either side. These connections between the tunnels and the draft duct are provided with valves, or slide dampers, by which the connection can be opened, or shut, or regulated.

When the gases from the fire have traveled through the tunnel to the point where they become cooled down nearly to their dew point, the valve in one of the connecting ducts is opened, and they are carried off through the main draft duct. The paper partitions burn away when the heat gets sufficient, and as each partition disappears the draft valve next ahead of it is opened to carry the gases into the new chamber just connected.

The length of tunnel under operation at once varies, but usually is the equivalent of seven, eight or nine chamber lengths, or from one hundred and forty to two hundred feet. In some kilns this may be shortened down somewhat, but less than one hundred and forty feet is apt to mean that the fullest heat economy is not being attained. The number of chambers ahead (i. e., in the direction the draft is going) of the firing chamber is usually four or five. Three is too few and rarely can the gases be passed through more than five chambers, or an equivalent length of straight tunnel, without being chilled to their dew point, beyond which it is not feasible to use them without heavy damages from staining, scumming, efflorescences, kiln marking, etc. The number of chambers (or equivalent length of tunnel) behind the firing chamber is usually three to five, the number depending on the temperature of the incoming air.

The air passing through the cooling wares can usually be brought to a temperature of 900° to 1000° C., before any fuel is used in heating it to a higher point in the firing chamber. The gases passing from the firing chamber usually drop in temperature from the finishing point to about 900° to 1000° C. in the first chamber, 600° to 700° in the second, 300° to 400° in the third, 100° to 200° in the fourth, and 50° to 125° in the fifth.

The fuel used is from one-fifth to one-third of the amount used in an ordinary periodic kiln of good construction. One quarter represents the average amount.

In the foreign countries where fuel is very expensive, the continuous kiln now has the most frequent use. All classes of ware, from the most common brick to porcelain, are burned in continuous kilns. It was stated by one of the firms mentioned above that their continuous

kiln was carried through a month's burning on a single car load of slack coal, weighing about thirty-five tons. However, this figure would vary widely with the necessary temperature to be obtained, the weight of the wares to be heated, etc.

The greatest objection to the continuous tunnel kiln is the lack of control over the course of the draft. The natural tendency of heated air is to rise, and as the draft in the kiln is necessarily horizontal, the gases are sure to tend to flow along the top or crown of the kiln, over-burning the ware at the level and underfiring the lower portion of the setting.

Another trouble, often serious for the manufacturer, occurs in the tunnel kilns. The usual mode of firing is by dropping the fine coal or "slack" through holes in the roof, through the vertical checker-work flues before mentioned. The rapid combustion of the coal in small pieces, especially at temperatures below the highest reached, tends to liberate the coal ash in feathery, flying particles, which are picked up by the draft and carried along, lodging in eddies of the draft on the surface of the ware. All coals do not cause this difficulty equally. Some tend to fuse and stick together, and in this case the difficulty takes a new form—that of cleaning and reusing the checkers. The expense of setting up and taking down the checker work is to be considered also. With a kiln of this type it is a very difficult problem to burn glazed ware, largely due to the dust or ash settling on the sticky surface of the molten glaze.

Haigh Kiln.—The Haigh Kiln is one of the continuous variety, but it differs from most others in that the fuel is fed into fire holes on the exterior of the kiln wall, instead of being dropped in among the ware as just described. The kiln is usually built in a U shape, with duct connecting the two extremities. This open court permits of having doors for loading and unloading the kiln on both sides of the tunnel, and as the tunnel is fired from both the top and the sides it permits of an equal distribution of the heat over the cross section. The chambers are marked off by drop arches which come down into the kiln a matter of a foot or more, and act as a check or baffle to the gases flowing along the crown of the arch. The side firing is advantageous, in that it has a tendency to help bring up the temperature of the floor of the kiln equal to that at the top.

The same objections apply in general to the Haigh kiln as to the kiln first described, but it has some advantages over the other in the ease of heat distribution and less flying ash.

As stated earlier, the Haigh kiln in this particular instance is being used for burning roofing tiles and dry-press bricks in the same chamber. This is a practice not to be endorsed. Clay which has been worked in the plastic condition will develop a vitreous structure at a lower temperature than the same clay worked by the dry process. And again a thin

piece of clay ware can be fired in a shorter time than a thick piece. Hence, the idea of nesting thin plastic wares like tiles among dry pressed bricks, and expecting to burn both at the same time, is entirely wrong. One or the other must suffer as a result. It would be much better to set one chamber of bricks and another with tiles, for then each ware could be given a somewhat modified treatment in firing.

In summing up, neither of the continuous kilns mentioned can be said to be doing particularly high grade work in burning roofing tiles, but there is no reason why the continuous kiln cannot be made ideal for the burning of roofing tiles in this country as well as in Germany and France.

The proper kiln should be rather low, and not very wide; the fuel must not be distributed among the ware, but should be burned in separate furnaces, and fed to the kiln chamber as a gas.

The draft must be under full control by dampers, and should be created mechanically, so that it can be made constant or varied at will. The cooling chambers should be so arranged as to furnish heat for the drying and to assist in warming up the newly set tiles, before the combustion products are admitted to them. While the continuous kiln composed of separate chambers is more expensive to build and keep in repair, it will be found better for the burning of roofing tiles. The construction of a continuous kiln should be in the hands of a properly trained engineer. The problems involved are too numerous and varied to make it at all a safe thing for a clay worker to attempt, unless prepared as a constructing engineer.

SUMMARY.

In considering the best type of kiln for a roofing tile plant, the size of the plant and the provision for the regularity of operation are naturally of paramount importance. For small plants, with but little capital, and without means for storing up a winter's supply, or wet weather supply of clay, investment in a continuous kiln would not be at all warranted. It must be kept in constant operation, or its economy and its convenience disappear. The small, cheap, and autonomous periodic kiln has far the advantage for such a plant, even though it uses three or four times as much fuel. Among the periodic kilns, the rectangular are to be preferred to the round, on account of economy of space in setting. The draft distribution can be made virtually as good, and the slightly increased losses of radiation and slightly more costly building of the kiln will not be serious items in the cost of the product.

In large plants with ample capital, good clay storage, or a supply independent of weather, the continuous kiln, with all of the best devices for preventing poor draft distribution, using waste heat of cooling ahead

of the combustion gases, using furnaces which will prevent flying ash, and using mechanical draft, is unquestionably the proper one to install. The reduction in the cost of burning is what should control, where quality is not at the same time sacrificed. The roofing tile manufacturer, in order to compete with lower-priced roofing materials, will soon be compelled to make tiles cheaper than can be done in many existing plants.

The final cost of production can generally be best reduced by studying to handle the burning with ease and certainty and with the minimum quantity of fuel of the less expensive sorts.

CHAPTER X.

ROOFING TILE SLIPS AND GLAZES.

The coloring or glazing of roofing is not at all new. The art dates far back into history. Probably the oldest example we have of glazed tiles, are those from the temple of Hera, which was built about one thousand years B. C.[1] According to Graeber, in a memoir, these old tiles were covered with a black glaze. It is probable that the covering was a black slip like that used on Grecian pottery, and not a true glaze, as understood today.

Kashiwagi,[2] a Japanese antiquarian, of Tokio, has records of a green glazed tile of the normal pattern, which he claims is over one thousand years old. Morse also records the finding of tiles covered with a brown glaze at Bizen, Japan, known to have been made at least two centuries ago.

Persian[3] roofs from the thirteenth to the fifteenth centuries were covered with highly glazed tiles. While a few glazed tiles have been made in this country for many years, it has only been within the past decade that any particular attention has been given to the subject. With the introduction of polychrome architecture, there has been an increasing demand for glazed tiles in the various colors, largely greens.

SLIPS AND ENGOBES.

The coatings known as slips (in German and French, engobes) and those known as glazes, differ merely in degree of fusion. A slip is a coating, applied to a clay ware, which does not fuse in the subsequent burning process. It is usually a clay, or a mixture of natural clays, which on firing, preserves a burnt clay texture on its surface and fracture, and does not soften to the point of flowing, or assume the smooth surface of a fluid. It may be soft and porous, or steel-hard, or even vitreous, but its changes have been such as occur without flowing, or mingling by movement while at high temperatures. As stated before, slips as a rule are natural clays or mixtures of such, which vitrify at low temperatures, forming a more or less impervious coating. The purpose of a slip may be two-fold: 1st, to give a desirable color to a clay of otherwise undesirable color; 2nd, it may be used to give a smoother surface by filling up irregularities, and thus getting a tile which will remain clean longer.

[1]Morse, E. S. American Arch. & Builder, 1892. Vol. 36, p. 7.

[2]Ibid. Vol. 36 p. 5.

[3]Encyclopedia Brittanica. Ninth Edition, Vol. XXIII, p. 389.

Roofing tile plants using calcareous, glacial or alluvial clays, which on burning develop a light-pink, buff or greenish mustard color, are practically compelled to make use of slips to mask or cover the surface of their wares.

Natural Slip Clays.—For ordinary slip coloring, the requirement is for a clay which will easily disintegrate and beat up to a state of fluid suspension in water; which is naturally very fine grained; which will not shrink too much in drying, and hence will not crack or peel when applied in a thin coat to another clay already partly or wholly dried; which possesses a fine red color, when matured at a low temperature (900° C. or below), and remains good to as high a temperature as the body to which it is to be applied will require in burning; which develops a more or less glossy, but not glassy, surface; which will naturally wash clean by rains and offer the minimum opportunity for the lodgment of soot and dirt. Such clays are not common, and when found, acquire a certain value as a commercial commodity, being bought and sold by the ton or barrel. Good ones are sometimes even imported from Europe.

Two of the American plants are using the Helmstedt clay from Germany, which burns to a fine red at a low temperature. To cheapen the cost of the slips it has been the practice of late to substitute a part of the foreign material by some local clays. There is no reason why slips composed wholly of local clays could not be used. Two clays have been tried in an experimental way in the Department of Ceramic Engineering of the Ohio State University with promising results. One is found a few miles east of Columbus, and is known as the Bedford shale. The other is a soft shale from South Webster, Ohio. Both clays, when made into slips, burn to a very beautiful cherry-red color at their respective finishing points. The Bedford shale has a longer heat range than the South Webster shale. The drying shrinkage in each case is a little high, but by using a part of the clay in a calcined condition, and ground to an impalpable powder, this point could be corrected to fit any average roofing tile clay. While the Bedford shale in the quarry is in so hard a condition that it would need grinding and screening before it could be blunged into a slip, the weathered outcrop of it will often yield great quantities of fine soft clay which will blunge without grinding. The South Webster shale, as seen so far, could be blunged into a slip direct from the pit, but it would also probably need grinding when mined well under cover.

The usual practice at plants where slip clays are used is to ship in a considerable quantity of their slip clay once or twice a year, and store it in a dry condition, each day taking what is needed. This is put into a blunger, where water is added, and the charge blunged or stirred until the clay is thoroughly broken up and suspended in a thin, creamy condition. It is then sieved through a screen of from forty to one hun-

dred meshes per lineal inch, and stored in barrels or tubs, where it is allowed to settle. The supernatant water is then tapped off until the slip has the proper density. This varies, however, with each clay. A tub of the prepared slip is placed upon a bench at the end of the dryer, from whence the dry tiles are being taken. In some cases the slip is poured over the outer or face side of the tile only, by means of a dipper. In other cases the entire tile is immersed in the slip for an instant, not long enough to soften, but long enough for a layer of the suspended clay particles to be deposited on the tile by the absorption of the water. As soon as the tile is removed the water soaks into the tile, and it apparently dries, usually in a minute or two. The tiles then go direct to the kiln for setting.

In the past much controversy has occurred over the use of slips. This has come very largely from faulty slips and the misuse of the same. There can be no more objection raised to the use of slip clay on a tile than there can to the use of a true glaze, and in some respects not so much. The slip coat should be used as a true means of decoration, however, and not to hide a poor tile.

The application of a slip coat over the surface of a whitewashed tile is sure to end with bad results. The scum acts as an insulating barrier to the slip, preventing it from coming in contact with and fluxing fast to the tile body. Hence, in a short time after such a tile is exposed to the weather, water gets beneath the slip, and on freezing, shells or pushes it off. A very noticeable example of this defect can be seen on the roof of the Art Museum in Eden Park, Cincinnati, Ohio.

It has been claimed by makers of slipped tiles that their product does not become dirty on the roof as unslipped tiles do. This point applies chiefly to tiles of porous body. It does not apply to strictly vitrified tiles, which wash as clean with rain as any clay surface, glazed or unglazed.

The reason that a slipped porous tile will remain clean is that the slip, on becoming vitreous, or vitrified, acts in a sense like a glaze, allowing the tile to be washed clean by rains.

If for any reason a manufacturer has selected a clay which in itself does not burn to a good color, but otherwise makes a sound, perfect tile, there can be but one objection to his using a slip to give him a red color, viz., the chipping of the tiles in transportation and handling reveals the body color beneath the red surface, and makes an unsightly blotch on the color. This objection holds equally true for any kind of superficial coat, glaze, enamel or slip. The objection is of much more real weight in pottery and other wares which are to be handled at close range, than to a roofing tile or building terra cotta, which is ordinarily so far removed from the eye that small imperfections become invisible. Much injustice has sometimes been done in applying too exacting stand-

ards to the judging of these wares. Obviously the soundness of the body and the appearance of the product when in position are the two important criteria, and defects which cannot be recognized or seen, and which have no effect on the life of the product, should be ignored. On the other hand, there are strong economical objections to slipping—the cost of the slip clay itself, its preparation, the expense of applying the same, with the resultant breakage of a percentage of the tiles, which will certainly take place during the shipping, are all to be considered. There are so many natural red burning clays of excellent color that it would seem entirely unjustifiable to locate on and use a clay for roofing tiles which must be given a coating of slip to cover up its poor color. In localities where natural red burning clays are lacking it may be justifiable, but not elsewhere. The plants now compelled to use a slip on their tiles were in most cases established without adequate knowledge of the roofing tile business or of the clays they were to use, and the present owners as a rule have bought the plants in at forced sales after heavy losses had been incurred by their projectors. The present owners have, therefore, to make the best of what they have, and use slip as one way of doing so.

The use of a clay naturally burning to any other color than red is not known in the American roofing tile industry. It is a very common and important process in terra cotta manufacture, where every shade of browns, grays, yellows, whites and speckled mixtures of the same are used. There is not much more difficulty in obtaining clays which will form desirable light-burning slips than for red-burning slips, but the market now offers no opening for such materials.

Artificially Colored Slips.—The commonest practice in coloring slips has been to attempt to produce a better red color by use of oxide of iron in the slip. Sometimes salts of iron, like copperas, are employed. As a rule such attempts fail, either when applied to the slip coating alone, or to the entire body of the clay. As a rule the expense of such a course is too great, and the results are not satisfactory as to the color obtained. Instead of getting a good red, most generally a brownish or dirty gray is secured. Red oxide of iron changes to dark brown or black on heating, and does not act as a red pigment. Iron can be introduced in other forms which will color a clay red, but its use is costly and also leads to other defects. Manganese oxide can be used with success, but the color produced is dark, not red, and the expense again comes into serious consideration.

The use of colored slips other than red for roofing tiles has been up to the present practically unheard of. One plant, The Bennett Roofing Tile Company, of Baltimore, produced on a small scale a few shades of green in true slips, during the latter part of its career, but at no other plant was anything of this sort being attempted in 1908.

The use of colored slips for roofing tile is sure to come, however, and with its advent will be opened up a wonderful field for polychrome decoration to the architect. With colored slips, a soft delicate appearance, so much desired and but poorly imitated by most glazes, is available. Where stained wooden shingles are now used for roofing and siding purposes, it will be possible to use an everlasting absolutely non-fading material.

For dark colored slips, such as browns and blacks, the same clay that is being used for the body of the tiles, or any good red-burning slip clay may be used. By blunging into this clay, or better still grinding the clay to a cream with various per cents. of iron oxide for the browns, and with manganese oxide and a small amount of cobalt oxide for the blacks, these colors are readily secured.

The amount of coloring matter will depend upon its source and fineness of grain. For oxide of iron, there are two sources of supply, *first*, the natural red hematite or limonite ores, which yield a fine red color when ground to a powder. Of these the "Clinton Metallic," ground from the fossil Clinton iron ore of New York state, is an excellent type. There are several such on the market. Analysis of this ore, as furnished in ground condition for "mortar colors" and similar uses is—

Siliceous matter	15.37
Aluminium Oxide	4 42
Ferric Oxide	62.08
Calcium Oxide	6.85
Magnesium Oxide	3.15
Water and Carbonic Acid	8.08
Total	99.95

Second. "Venetian red" is produced by the calcination at low temperatures of ferrous sulphate, or copperas, or iron vitriol, which is a by-product in enormous quantities in the pickling vats of tin-plate mills. This copperas at lowered heat gives off its water and sulphuric acid and the spongy ferrous oxide remaining oxidizes into red ferric oxide, of great beauty of color. It is, however, always impregnated with undecomposed sulphuric acid salts, and is a fruitful cause of scumming in consequence. In composition, it is nearly pure ferric oxide, but its impurities are very detrimental.

Manganese oxide can be obtained in abundance from a number of dealers in heavy chemicals in this country. It is prepared for the brick trade, especially, in sizes ranging from twenty to thirty mesh granular powder, up to the finest floated pulp which cannot be measured by a screen. The commonly used sizes are twenty to thirty, forty to fifty, sixty to seventy, ninety to one hundred; and the floated or paste form. These powders are mostly ground ores of manganese, pyrolusite, wad, or psilomelane. They vary pretty widely in composition, not

only from brand to brand, but also in the same brand. The most reliable brands are said to be English and German, which vary very little in their character. The American producers can undoubtedly produce an article of the same quality and uniformity whenever they appreciate the necessity of doing so. Up to the present, they do not all seem to see the need of strict uniformity and chemical control of their output.

The composition of a standard brand on the market, as furnished by the courtesy of The Harshaw, Fuller & Goodwin Co., of Cleveland, Ohio, is as follows:

Analysis of Manganese Oxide.

Ingredients.	Ordinary.	Selected.
Peroxide of Manganese	84.44%	85.42%
Protoxide of Manganese	0.50%	0.83%
Peroxide of Iron	0.93%	0.86%
Oxide of Lead	None	None
Oxide of Copper	0.02%	0.02%
Oxide of Nickel	0.05%	0.05%
Alumina	1.71%	1.06%
Barytes	1.21%	1.41%
Lime	1.15%	0.88%
Magnesia	0.18%	0.04%
Potash	0.22%	0.21%
Soda	0.68%	0.58%
Silica	5.60%	5.45%
Carbonic Acid	0.70%	0.50%
Sulphuric Acid	0.418%	0.555%
Phosphoric Acid	0.360%	0.330%
Arsenic	None	None
Combined water	1.90%	1.75%
Totals	100.068%	99.945%

For the other colors, such as buff, yellow, blue, green, gray, white, etc., it is necessary to start with light or white-burning materials as a base, to which the various coloring oxides can be added to give the desired color.

The first problem is to prepare a white engobe or slip which will fit the roofing tile body and at the same time vitrify sufficiently to cause it to adhere tightly. It must not be so vitreous as to have a glassy surface or sheen.

An ordinary white engobe prepared of the following ingredients will require a much higher temperature to vitrify it than the average red-burning roofing clay will stand.

Kaolin	150
Flint	100
Feldspar	50

Hence, to soften it down to a point where it will vitrify at the desired temperature, a flux must be added. The one most available is some form of lead, either white lead (the basic carbonate) or an oxide, like red lead. Other ingredients, such as lime, more feldspar, or feldspar of more fusible variety, may be added to assist in lowering the vitrification temperature, but they are not sufficient without the use of lead.

After a white engobe has been obtained which will sufficiently mature and harden at the rather low temperatures at which the red roofing tile body-clays mature, and which fits the body as to shrinkage, the production from it of a series of colored engobes is a comparatively simple task. It is only necessary to add the raw coloring oxides to the base engobe, grind them fine together, and apply as an ordinary slip. The great advantage in favor of using slips instead of glazes is that the tiles can be faced or set in the usual way, no attention being necessary to prevent them from sticking. For other reasons to be discussed later, it is firmly believed and strongly advocated that the roofing tile manufacturer should devote more attention to slips than to any other mode of tile decoration or coloration.

At the laboratory of the Department of Ceramic Engineering of the Ohio State University, slips of a few of the more common colors have been developed with good success after being fired in an experimental way in the University kilns, and finally in the actual roofing tile kilns at several plants. It is deemed safe to give them out as starting points for others to use in developing similar slips for their own purposes.

Base Engobe.

White Lead (basic Carbonate of Lead)	17.80
Soda Feldspar from the Sparvetta Co.	25.40
English Whiting (Carbonate of Calcium)	1.90
Edgars Washed Florida Kaolin	39.70
Golding's Ground Silica (Potters' Flint)	15.20
	100.00

This mixture, well ground together in ball mills, and passed through a one hundred-mesh screen and fired at cone 02, becomes steel-hard, though it does not run or fuse in the least. It is of a creamy white. A better white might be secured by varying the kaolin, and perhaps the other minerals above. Coloring oxides can be added, however, without being at all affected by the lack of purity of the white color of the base engobe.

A good green was produced by adding ten per cent. (dry weight) oxide of chromium to the above base engobe.

A good yellow was obtained by adding ten per cent. of oxide of uranium.

A good light blue was produced with from two to three per cent. and a dark blue with six to eight per cent. of cobalt oxide.

Some excellent greens were produced by blending various proporions of the uranium engobe with the chromium engobe. The colors obtained were yellow or olive greens.

The amounts of the coloring oxides used in the above formulas are large, and hence the recipes would be expensive to use on a large scale. But the experiment has not been carried to its completion, and doubtless great improvements can still be made. For instance, instead of using the pure oxides direct, it would be better to mix them with glass-forming materials, and fuse them into a melt or fritt. These fritts, containing from twenty-five to fifty per cent. of the coloring oxide, and being themselves of a fusible nature, could then be ground to a very fine powder and added to the engobe. The result would undoubtedly be to obtain a more lively color with much less coloring oxide, and resulting economy. The details of these fritts have not been worked out, but in general, if soda, borax, a little lead, and a little potters' flint be used as a flux, the coloring oxides will dissolve or amalgamate freely. The proportion can be easily worked out by a few trials. The melting should be done in crucible furnaces where the materials can be kept covered and kept under treatment as long or short a time as is needed. The melts should be poured into water to crackle, then dried, and ground to an impalpable powder before use.

The work of properly fritting and making colored slips or glazes should be in the hands of a competent person, who has had training in ceramic chemistry. If the work is carried on in a systematic and economical manner, much money can be annually saved, which is now wasted in obtaining ceramic colors without a knowledge of the proper ingredients.

GLAZES.

The fundamental requirement of a glaze, as distinguishing it from a slip, is its fusibility at the working temperature. A hard glaze suitable for a body requiring a high fire, might act as a slip if applied to another body maturing many cones lower, and so also, a satisfactory mixture for a slip at a low heat, might fuse to a glaze if carried much too high. But, if the substance is not more than a vitrified solid when finished, it is a slip, and if it has been fused, it is a glaze. Of course, there are all manner of intermediates, which it is difficult to refer to either class with certainty.

Glazes are divisible into two main groups—the bright or glassy and the dull or stony. The former include the transparent glassy glazes, of the kind employed in table wares, and the opaque glazes known as enamels. The latter include the so-called matt glazes, and

certain others which are known as crystalline glazes, though they are also matt. Between the transparent brilliant glassy glazes, and the dead, lusterless stony matt glazes, every possible gradation of luster, color, and surface texture may be found or produced, and it is impossible to classify all of these intermediates with accuracy into either one or the other of these divisions.

Bright Glazes.—These glazes are the common or typical kind of silicate surface coating. For a long time they were almost the only kind made. Dull or matt glazes were only produced as failures in the attempt to get bright ones. But as has happened many times before, man has converted his failures into successes, and in the last few years the use of the dull glaze has greatly increased. From the artistic point of view, as a coating for roofing purposes, bright glazes are now considered a complete failure. The reflection of light from their mirror-like surfaces is so strong under ordinary conditions that it is impossible to look at the roof, except at certain angles. The color cannot be seen at all, except on dull days or from special points of view. This very practical difficulty led to the introduction of the matt or dull glaze into the roofing tile field.

Nevertheless, roofs have been covered with bright glazed tiles, and doubtless will be again. The general type of the glazes employed is known as the raw lead glaze, and usually the more fusible varieties are required, as the red burning tile clays mature at relatively low temperatures.

Such glazes may be represented in chemical formulas as between the limits—

$$\left.\begin{array}{l} 1.00 \text{ to } 0.50\ PbO \\ 0.00 \text{ to } 0.20\ K_2O \\ 0.00 \text{ to } 0.20\ CaO \end{array}\right\} 0.10 \text{ to } 0.25\ Al_2O_3 \left\{ 1.25 \text{ to } 2.25\ SiO_2 \right.$$

The ingredients most commonly employed in making such glazes are

Red Lead or White Lead.
Feldspar or Cornish Stone.
Whiting
China Clay or Ball Clay.
Flint

A typical raw lead glaze, falling within the above limits, which will melt and run bright at a temperature beginning about cone 08, and which will often remain good to a temperature as high as cone 02, has a formula as follows:

$$\left.\begin{array}{l} 0.85\ PbO \\ 0.05\ K_2O \\ 0.10\ CaO \end{array}\right\} 0.10\ Al_2O_3 \left\{ 1.20\ SiO_2 \right.$$

This glaze (No. 1) could most easily be made up of the following ingredients:

$$\left.\begin{array}{ll} \text{White Lead} \ldots & 68.98 \\ \text{Ground Feldspar} \ldots & 8.74 \\ \text{Whiting} \ldots & 3.14 \\ \text{China Clay} \ldots & 4.05 \\ \text{Potters' Flint} \ldots & 15.09 \\ \hline & 100.00 \end{array}\right\} \text{Unit weight 318.}$$

Another typical raw lead glaze, which will mature at a little higher temperature, beginning at about cone 05 and remaining good to cone 01 or 1, is as follows:

$$\left.\begin{array}{l} 0.70\ PbO \\ 0.15\ K_2O \\ 0.15\ CaO \end{array}\right\} 0.20\ Al_2O_3 \left\{ 1.90\ SiO_2 \right.$$

This glaze (No. 2) could most easily be made up of the following ingredients:

$$\left.\begin{array}{ll} \text{White Lead} \ldots & 52.10 \\ \text{Ground Feldspar} \ldots & 24.00 \\ \text{Whiting} \ldots & 4.50 \\ \text{China Clay} \ldots & 3.80 \\ \text{Potters' Flint} \ldots & 15.60 \\ \hline & 100.00 \end{array}\right\} \text{Unit weight 345.9}$$

A third typical raw lead glaze which will begin to mature at about cone 02, and will remain good to about cone 3 or 4 is as follows:

$$\left.\begin{array}{l} 0.60\ PbO \\ 0.20\ K_2O \\ 0.20\ CaO \end{array}\right\} 0.25\ Al_2O_3 \left\{ 2.00\ SiO_2 \right.$$

This glaze (No. 3) could most easily be made up of the following ingredients:

$$\left.\begin{array}{ll} \text{White Lead} \ldots & 45.40 \\ \text{Ground Feldspar} \ldots & 32.61 \\ \text{Whiting} \ldots & 5.86 \\ \text{China Clay} \ldots & 3.78 \\ \text{Potters' Flint} \ldots & 12.32 \\ \hline & 99.97 \end{array}\right\} \text{Unit weight 340.9}$$

By taking fractional parts of a unit weight of either glaze, any desired mean between any two may be obtained, viz:

$$\begin{array}{lr} 0.8 \times 318 \quad \text{(unit weight of No. 1)} = & 254.4 \\ 0.2 \times 340.9\ \text{(unit weight of No. 3)} = & 68.18 \\ \hline & 322.58 \end{array}$$

which makes a glaze (No. 4) one-fifth of the way between the two extremes, and which will be harder than No. 1 by about one-fifth of the difference in fusing point between No. 1 and No. 3.

With these starting points, a little experimenting will often lead to the production of a satisfactory simple, bright, raw-lead glaze. When the problem involves fitting the glaze to a body, and remedying crazing and other defects, or matching colors, the matter becomes too complex to deal with by rote, and it should be put into the hands of one acquainted with the theory of the subject.

These mixtures all mature at their respective temperatures to form bright transparent glazes. If applied over a red body, the red color will show through; if over a buff body, the glaze will appear yellow, though the yellow is due to color of the buff body showing through the clear glaze.

Should it be desired to make a glassy green glaze, using one of the above type glazes, it would only be necessary to add various per cents. of copper oxide. It will, however, be found impossible to produce satisfactory bright green transparent glazes over a red body direct. The red color of the body will show through and interfere with the desired color. To overcome this, it is necessary either to use an opaque glaze or enamel, or else first to slip the tiles with a white or buff slip or engobe and then apply the colored transparent glaze upon them. The true color of the glaze will then persist.

The amount of copper oxide required to make one of the above glazes into a good strong green is about one and one-fourth per cent. Lighter tints are obtained of course with smaller quantities, even one-fourth per cent. will be quite clearly green, on a clear light background. No advantage will be found in running the copper higher than two per cent., unless it is desired to produce bluish "gunmetal" effects, in which case the amount may have to be three per cent. or above.

A number of plants are making a very satisfactory bright glaze, variously known as "red brown," "fox red," "mahogany" or "tea-pot." This glaze, to be at its best, should be applied on a body which naturally burns to a light red or pink, and requires a red slip to strengthen its color to a saleable point.

The base of the glaze can be the same as any of those just given. To it is added one per cent., or a little less, of iron oxide, or better still from two to three per cent. of manganese oxide. The glaze when applied over the red slip coating of the tiles seems to dissolve or take into solution parts of the slip clay, thus allowing the color of the main tile-body to show through feebly in irregular streaks, while the parts not dissolved show a dark red color. The combination of the light and dark red presents the appearance of the grain to be seen in mahogany wood.

These red-brown glazes nearly all show beautiful spangled crystals in places—not on every tile, but in frequent instances. These crystals are due to the excess of the iron dissolved in the glaze. The glaze while fluid takes up the oxide of iron from the slip clay in addition to what

has already been added, and becomes supersaturated, so that upon cooling small glittering flakes of some iron compound crystallize out.

Other colors which can also be produced from these same glazes are plain blue with oxide of cobalt, plain brown with oxide of manganese, and plain orange yellow with oxide of uranium. The cobalt is a very powerful oxide, and only a few tenths of a per cent. are needed. Uranium is also used sparingly on account of its cost. One per cent. or less is as much as would be used ordinarily. Manganese produces a fainter color and several per cent., even up to five per cent., may be needed. Of course, mixtures of the different oxides produce mixtures of their colors—cobalt and copper produce blue-greens; cobalt and iron produce black; cobalt and manganese produce purple, etc. The field open to the experimenter in producing new shades is practically endless.

Matt Glazes.—With the introduction of the dull glaze, which does away with the painful brilliance of the early types, has come a much wider use of glazed tile roofs. Color schemes are now possible which could not be realized with bright glazes, or which could not be seen even if produced.

The true matt glaze is one whose chemical composition is such that on cooling it cannot retain a glassy structure, but changes to a stony or crystallized mass instead. There is a group of matt glazes which are not to be distinguished readily from true matts, but which are merely immature or partially fused. These come very close to slips or engobes, though generally they are more completely fused than the latter. The true matts, however, are much more satisfactory to work with, have the widest temperature range, give the best colors and leave fewer defects in covering the ware properly.

The surface of the true matt glaze is crystalline or rough, often not to the eye or the feel, but if examined closely with a glass it would be seen that the surface resembles the peel of an orange or an egg shell. This roughness causes an absorption or breaking up of rays of light, instead of a reflection back as from a mirror, so that what the eye sees is a solid mass of color, soft and velvety to look at.

The roofing tile manufacturers have not found it a very easy task to produce matt glazes of satisfactory color and surface texture, which would mature at the low temperatures at which they are mostly compelled to work. Matt glazes in other industries, maturing from cone 2 up, are common, but the latter are expensive fritted glazes, not suitable for a product like roofing tiles. In order to bring the maturing point of the cheaper matt glazes down to about cone 06 or 05, more fluxing ingredients like lead oxide have had to be resorted to, and with this increase has come trouble from the glaze drying up through volatilization when fired in the open kilns, and also bright glazes are produced by a little extra heat, and the matts would vary in degree of their mattness.

The following formulas have been tried on several roofing tile clays with a fair degree of success. They require about cone 02 to mature, which is a little higher than desirable:

$$\left.\begin{array}{l}0.70\ PbO\\0.10\ K_2O\\0.20\ CuO\end{array}\right\}0.34\ Al_2O_3\left\{1.60\ SiO_2\right.$$

Add 0.10 to 0.12 CuO for color.

This glaze (No. 5) can most readily be prepared by grinding together the following batch:

White Lead	50.80
Ground Feldspar	15.40
Whiting	5.50
China Clay	17.05
Ground Flint	8.65
Copper Oxide	2.60
	100.00

This glaze gives a rather light green matt, which would be improved with a little more yellow color.

A glaze which will mature at a slightly lower temperature, about cone 05, is given below.

$$\left.\begin{array}{l}0.45\ PbO\\0.12\ K_2O\\0.35\ CaO\\0.08\ ZnO\end{array}\right\}0.28\ Al_2O_3\left\{1.90\ SiO_2\right.$$

Add 0.12 CuO for color.

This glaze (No. 6) could most readily be prepared by grinding together the following batch:

White Lead	36.40
Ground Feldspar	20.80
Whiting	10.85
Zinc Oxide	2.05
China Clay	12.80
Ground Flint	14.15
Copper Oxide	2.95
	100.00

This glaze produces a matt green, and on account of the lead content being lower than No. 5, it should stand the heat treatment with less volatilization. If the copper oxide is left out of the glaze, it will be a rather yellowish white and not at all pleasing. In the place of the copper oxide various amounts of cobalt oxide may be added for blues, iron oxide and uranium oxide for yellows, manganese carbonate for purples and browns, and nickel oxide for gray. The amounts of the various oxides to use will vary, but aside from cobalt, which requires very little, the quantities are not very dissimilar to the amount of copper used in the preceding batch.

Beside the production of matt glazes by the proper means; viz., proportioning the ingredients correctly and giving the glaze the proper

heat treatment, there are a number of ways of dulling the surface of of a glaze and thus producing what for lack of a better name we may term artificial matts. One of these processes is to add raw sand or ground calcined clay into matt glazes in various per cents, giving the glaze a very rough and stony appearance. For some purposes this method, it is believed, has decided possibilities for good. In reproducing the moss-covered tiles so much admired in Europe, this is probably a good mode of attack.

A similar mode consists in artificially roughing the surface of the clay by cutting it with a wire, and allowing the rough surface formed by the dragging of the grains to remain unsmoothed. This of course could only be applied to flat tiles like shingles.

Another method is the use of the sand blast on the surface of a bright glaze. The glass is cut away, leaving a rough dull finish, very much liked by many architects for certain color schemes. The blasting machine is the same as is used by the glass manufacturers in producing etched or frosted glass. It consists of nozzles through which a powerful current of compressed air is blown, carrying sharp glass sand in suspension. This sand strikes with such force that it readily cuts away the surface of any substance, metallic or non-metallic. The tiles to be treated are laid together the same as if placed on the roof, on an endless belt, which moves very slowly, carrying them under the nozzles of the blasting machine. The speed requisite to allow the sand to cut away the surface of the glaze as the tiles pass by is determined by experiment. The sand used must be renewed quite frequently, on account of its wearing away to dust under the severe treatment to which it is subjected. While this method is rather slow and costly, it gives a characteristic and not unpleasing finish.

Another and very objectionable way of producing a matt finish was found in use at one plant. Tiles with bright glassy green glaze were being washed with hydro-fluoric acid, one of the most powerful and dangerous acids known, whose special peculiarity is its power to attack silicates. The vapors or fumes of this acid are an irritant poison, and for this reason its use should be permitted only under special conditions, with the most perfect ventilation, and every precaution for the safety and health of the employes. Its use under other conditions and without these safeguards is little short of criminal.

This powerful acid when applied to a glazed surface at once attacks the silicates that have been formed, dissolving or disintegrating them until the surface is minutely rough or stony looking.

It is a curious fact that in cut-glass factories this same acid is used for the exact opposite effect; i. e., for polishing a piece of glass which has a dull or frosted surface after it has been cut. The difference comes in the lack of homogeneity in the glaze, some parts dissolving so much

faster than others, while glass is practically all the same thing and dissolves about equally.

The possession of the mere recipe or formula of a glaze which is in successful use in one plant is but a very small step toward the installation of a successful glaze in another plant. Some glazes are in use which can be applied to wares of considerable variety, and at a considerable range of temperature. But this is not the common thing at all, and most glazes have to be operated under such special conditions that they would be practically useless if transferred without alteration to another works. They are often traded or sold as if they were a commodity of value, and then subsequent failure gives rise to ugly suspicions or charges of bad faith in the transfer, whereas, in fact, the causes of the failure are purely natural.

The fitting of a glaze to a body, i. e., its adjustment so that its rate of contraction in cooling or its expansion in heating up are about like that of the body upon which it is borne, is one of the great stumbling blocks in the path of the glaze maker, amateur or professional. There are many factors entering into its settlement, but the commonest, most useful, and in most cases a sufficient mode of control is by variation of the silica content of the glaze. For instance, in Glaze No. 2, if the glaze were cracking or "crazing" on the wares when drawn from the kiln, the silica in the glaze might be cautiously increased. The higher the silica can be pushed, without sacrifice of other necessary properties, the safer the glaze is from this trouble. But too much silica might produce the reverse phenomenon of crazing. viz., "shivering," where the glaze flakes off, carrying chips of the body with it, and producing a very undesirable surface. The silica must be reduced to overcome this defect. These additions or subtractions of silica to a glaze may and probably will affect its melting point, and the results cannot be considered as proved until the glaze has been fired at the temperature it requires after its alteration. Very many errors are made in this way by glaze makers altering the glaze composition and failing to alter the heat treatment at the same time.

Besides the question of being made to fit, it should also be so constructed that it will have a relatively wide heat range; that is, it should remain workable and good over a considerable increase in temperature. In regular roofing tile kilns, the temperature from top to bottom sometimes varies as much as two or three cones, and a like difference may exist from side to center of the kiln. It is plainly seen that a glaze which passes through maturity and becomes overfired within the temperature range of one or two cones, will not prove at all satisfactory under such burning conditions. There should be at least a range of four cones in which the glaze is good, and even more would be better.

Mechanical Preparation of Glazes.—Every step in glaze production should be methodical and systematic. This does not mean that changes

may not be introduced, but that changes must not be allowed to creep in without the knowledge or consent of the glaze-maker.

Weighing Out.—Each ingredient should be weighed separately, one at a time, in a scoop or weighing box, and the weights counted and recounted. When dumped into a common receptacle, one ingredient on top of another, there is much more danger of the ingredients getting mixed in taking out excess quantities of one or the other. *The sum of all the ingredients, after assembling all in one receptacle, should be reweighed and the collective weight of the batch should equal the theoretical sum of the individual weights of the various ingredients.* If this custom is kept until it becomes instinctive and unconscious, many serious errors in the mixing room will be avoided.

Grinding Glazes.—In general, it is important that the ingredients of glazes should be most thoroughly blended by fine and intimate grinding together. Especially is this the case where coloring oxides are added raw to a glaze batch, because the glaze is almost certain to be "specky" if not ground. In fact, a better way to insure the fine subdivision of the coloring matter is to grind it with a small quantity of glaze, or of some one ingredient of the glaze, separately, until impalpable when tested between the teeth.

The prepared color slip may now be added to the glaze, and with comparatively little grinding become well distributed. The function of the grinding is to secure uniformity in distribution and uniformity in fusion. With coarse particles of dissimilar minerals making the glaze, the effect would be crude and patchy.

There have been; and doubtless will be again, instances in which very interesting and admirable color effects and surface textures on glazed wares are obtained by the use of unground or poorly ground glazes, or where some one ingredient is left unground or added to the mill just before a charge of glaze is removed as finished. But, in the broad way, there can be no doubt that it pays, from the standpoint of cost and perfection of product, to reduce the glaze to a fine-grained, homogeneous state before use.

On the other hand, too fine grinding is possible. Glazes may be ground so fine that they will crack and shrink in drying on the surface of the ware like a fat clay would, and these marks may not heal over in the subsequent fusion. In general, if a glaze is ground long enough so that it will pass through a sieve of 150 meshes per lineal inch without leaving any residue on the sieve, it is fine enough. If raw coloring oxides are to be added, they should be preground as fine as possible before adding to the glaze batch. This insures good color distribution, without necessitating such long grinding of the entire mass of the glaze.

The mills for glaze grinding are of two types, the old, familiar buhr-stone type and the recent ball-mill type. There is difference of opinion among potters as to which produces the glaze at less cost

in grinding, fineness being equal. It would be a laborious problem to definitely settle this contention. But it is certain that the quality of the work done by either is good enough. The ball mills are steadily replacing the older type, chiefly on account of their convenience and ease of cleaning.

Iron grinding mills, such as are used by paint grinders for incorporating dry paints and oils or varnishes, are occasionally used by glaze grinders, and also iron-ball mills.

For some colors, especially the dark ones, very little, if any, trouble would be experiencd from this practice, but for the light colors much trouble will result. The metallic iron of the mill is ground off by the continual rubbing of the discs or the impact of the balls, and enters at once into the glaze as a part of it. When the glaze is applied and melted, the iron will form specks and discolorations.

Ball mills of large size should be lined with vitreous lining of stoneware or porcelain bricks, while the smaller ones are usually made of solid porcelain jars. The balls used in large mills for the grinding of glazes are, as a rule, flint pebbles gathered on the beaches of northern France. These pebbles are usually oval in shape, well rounded, and vary in size from an inch to three inches in diameter. In the smaller mills the pebbles are usually marbles made of porcelain. The dust worn from the linings and pebbles of porcelain or flint-lined ball mills is composed of silica or silicates, and being similar to some of the ingredients of the glaze, is absorbed without ill results, but in unlined iron mills this is not the case.

The consistency, or thickness, of the glaze slip is a matter of importance. If too thick it will form clots, or "blobs," of glaze in spots and along edges and in corners. If too thin it will not form a thick enough coat without more than one dipping, and will thus cost more labor. No law can be laid down, either in weight per pint or in specific gravity by hydrometer, by which a correct thickness can be determined. Different glazes vary so much in ingredients that they do not weigh the same per pint when at exactly the same relative fluidity. For any single glaze, the weight or specific gravity is constant at the same fluidity, and these measures are easily available for the guidance of the men. The practical sense of the dipper is usually sufficient to keep the glaze about right in this respect. The application of the glaze to the ware is done in very much the same way as slips are applied. As the dry tiles come from the dryer, they are taken to the glaze room, where a large tub of the prepared glaze is ready. The tiles are then taken one by one, and coated on the outer surface by carefully pouring the glaze over them while held in a standing position, allowing the excess to drain back into the tub. The tiles are then placed on racks or shelves, to allow the glaze to dry sufficiently for handling.

The Setting of Glazed Roofing Tiles.—Glazed roofing tiles are at present set in very much the same way as the unglazed. In plants where the unglazed wares are set solid, without fire-clay supports or boxes, the use of boxes for the glazed part of their output is general. Only one plant was found in which glazed tiles were set solid, without boxes, and the results in this case were of a very low grade.

It is the usual practice to set the glazed goods in the lower half of the kiln, where they are more protected from the flame or flying coal ashes.

Figure No. 167 shows the method of setting glazed tiles in a kiln where the balance of the ware is set without supports.

General Discussion of Burning Conditions.—The limiting conditions of the glazed roofing tile business today is the one-fire burn. Manufacturers want to produce their glazes in the same burn with the regular ware. They think they are obliged to do this by the present prevailing prices for glazed tiles. The temperature required by roofing tile clay is usually relatively a low one, and the composition of the glazes that can be used is limited in consequence. None of the roofing tile plants are burning as high as cone 1 regularly, hence only fusible glazes are possible. Highly fusible glazes can only be commercially produced by use of lead oxide, boric acid in some form, or the alkalies, potash or soda. Of these, the alkali potash is expensive, and as it does not do its work materially better or differently from soda, it is practically out of consideration. Soda is abundant and cheap and effective, but it cannot be used satisfactorily in a raw glaze. It must be previously melted with silica, or some equivalent substance, and converted into a glass no longer soluble in water, in order to work well as a glaze ingredient. The cost of this preliminary melting or fritting, and the grinding which follows, makes the use of a fritted glaze objectionable.

Boric acid is open to the same objection as soda, viz.: solubility. A few insoluble forms could be made, but they are not commercially readily available, and moreover boric acid costs twelve to fifteen times as much as soda.

This leaves lead oxide as the chief, in fact the only really convenient and accessible resource of the glaze-maker for low temperature raw glazes.

Lead oxide is quite volatile at red heat and above, and its losses, depending upon the duration and temperature of the firing, are apt to be large. The longer the firing continues and the higher the temperature reached, the greater loss of lead from volatilization. This loss of the chief active flux brings about a rise in the maturing point of the glaze.

To prevent this glaze from becoming "too hard" by the volatilization of the lead, potters have long since adopted the plan of placing their ware in saggers, or fire clay boxes, the interior of which are well

coated with a glaze rich in lead oxide. These saggers are piled one above another and the joints coated with clay, making comparatively tight receptacles, so as the heat increases and the lead volatilizes, its vapors are held in the sagger, where they soon saturate the inclosed space and further volatilization is thus largely prevented. The ware itself is thus protected from the loss of much of the oxide lead from its glaze, because the "sagger wash" has already supplied all that the space will contain.

With the roofing tile manufacturer, the case is very different. He sets his ware in an open kiln, or at best in kiln boxes, where the lead oxide that volatilizes will be quickly carried out of the kiln along with the gases of combustion. There is no completion to the process of volatilization, because there can be no saturation of the moving current of air; therefore, it is necessary for the glazes to be loaded with a surplus of lead, to allow for the loss and to be sure that enough will remain.

Another trouble that very frequently happens in kilns using coal, is the sooting of glazes. The ware set in the open boxes becomes coated with soot or tarry matter in the early part of the burn. Now if the kiln should be burned pretty rapidly, or with a shortage of air, this deposited carbon will be caught and retained in the glaze. This may subsequently change the composition of some of the glaze ingredients and is very likely to ruin or spoil the glaze by forming bubbles, pin-holes and blisters. The potter, in saggering his ware, reduces and sometimes prevents the deposition of soot.

Many clays contain minerals, especially iron pyrites, that upon being heated give off gases. In the case of one-fire wares like roofing tiles, these gases pass through the coating of glaze on the surface, and in many instances give rise to bubbles in the glaze, as well as other defects. Single-fired goods are much more subject to this trouble than those which are "biscuited" in one fire, and glazed in a subsequent burn. The two-fire process however, costs very much more, and is now thought too expensive for roofing tile manufacture. Unless the manufacturer has a clay which will glaze satisfactorily by the one-fire process, he will either have to get a clay which will, or not attempt to produce glazed tiles.

It has been shown by experience that lead glazed goods should be protected from contact with the kiln gases, and to prevent volatilization they should be inclosed. Roofing tile manufacturers are doing neither. They are not only applying their glazes to a raw body, which is a handicap to the process of glazing, but are also setting the glazed wares so that they are subjected to all the changes taking place in the kiln fires, and generally in the bottom half of the kiln, where they get the moisture and waste gases from the wares above. Under these circumstances, is it any wonder that the losses are enormous on glazed

wares? They usually condemn the glazeman, change fuels, try every glaze receipt that comes within their reach, in fact do everything but the right thing.

While it is true that the roofing tile manufacturer should not undertake to set his glazed ware in saggers, he can at least burn them in separate kilns, designed for this particular work. Muffle kilns, built after the plan of those used by terra-cotta manufacturers, are the next and proper step in the direction of improved production of glazed roofing tiles. As a matter of convenience and economy, this kiln should be rectangular, narrow and low, and not of large capacity, so that it may be fired frequently, and thus not hold up orders requiring a small amount of glazed ware. It should be set with kiln blocks in the muffle, the same as in the regular kiln. The muffle merely acts as one big sagger, keeping the flame, soot and ash off the glaze, and at the same time confining the atmosphere inside the muffle, so that it might become partly saturated with lead vapors, thus reproducing or largely preventing the losses from volatilization of lead.

The roofing tile industry will never produce glazed ware in an economic manner, either as to cost or quality, under the present prevailing conditions. Those manufacturers that first grasp this situation, and properly equip themselves for the production of strictly first class glazed tiles at a price where they can be more widely used, will be the ones to get the business.

Comparison of Slipped vs. Glazed Tiles.—There are a number of advantages in favor of the production of tiles covered with colored slips, rather than with colored glazes, either bright or matt:

First. The slip is much less costly than the glaze, pound for pound, from the fact that much less lead is required.

Second. The slip has a wide heat range over which it is merchantable. The green slip, of which the formula was given earlier in this chapter, matures in the neighborhood of cone 02, but the same slip when fired to cone 8 still remained perfect, the only difference being that the color was better, and more intense, and the surface of the slip was smoother, bordering on a matt glaze. What is true of this slip is true of the class as a whole.

Third. The slips will not give as much trouble from volatilization or blistering or crazing or any of the common physical defects.

Fourth. The slip is much more likely to prove a durable coating, so far as the weather is concerned, when applied to unvitrified tiles. Seger says, "No one should use glazes, unless he knows that his ware has the necessary degree of durability to carry them. It is known that soft burned tiles, when they are exposed to the weather after glazing, generally shell off after a short time. Hence they are not improved by glazing. For this reason, it must be understood that

tiles must be hard burned if they are to be glazed, or at least medium hard, and it is better if they are vitrified, but under no circumstances should they be soft."

The reason for these statements can be very easily understood. A soft burned tile, which has an impervious glassy coating on its face side will have opportunity to absorb moisture from one source or another through its unglazed side. If this moisture freezes, it tends to force its way out of the tile in both directions from the center, and an enormous force is brought in play on the under side of the glaze, very frequently shelling or spalling it off. With a well vitrified tile, no such trouble will occur. The slip however is preferably not made entirely vitreous, and the water which freezes in the tile can escape through the slip the same as through the body, leaving both tile and slip unhurt. On well vitrified tiles, the slip should also be vitrified, but not glossy. No frost danger will come to any vitrified tile by reason of the use of either glaze or slip, but for a soft tile, a porous slip is the preferable coating.

Fifth. The slip coatings are duller in surface texture than any ordinary matt glaze can be made, and hence give the greatest freedom from reflection of light from the roof, and stand for their natural color in any and all lights better than a glazed roof can do.

Sixth. The setting of slipped wares is much simpler, as the surfaces should not become vitreous enough to stick. Glazed tiles offer a serious problem in this respect.

On the other hand, the advantages of the glazed tiles are:

First. They use less coloring material than slips will do to obtain an equal coloring effect, for the coloring oxides in the slip do not flux sufficiently to really develop their colors to advantage, and hence must be used in larger quantity. In the production of many colors this would be a serious item.

Second. The glazed tiles, even rough matts, if of good quality, will present an impervious surface to the weather and will not be readily stained by soot and dirty water which flows over them. A slip will ordinarily be porous enough to discolor easier from this cause, and cannot be cleaned again. Any surface, even of glass, is not proof against the gradual incrustation of greasy or tarry soot, and no roof will remain permanently clean and bright. But a well glazed tile roof can readily be cleaned by scrub brush, soap, and hose, and a slipped roof can not.

The periodic cleaning of glazed terra cotta and enameled brick buildings by washing is now becoming a recognized necessity if the true character of the surface is to be maintained, and in this connection roofs will also need the same treatment.

It is not the intention or desire to discourage the use of glazed roofing tiles. But if used, the plane of their manufacture should be raised, and they should be made as perfect in proportion as enameled bricks or glazed terra cotta, which is not now the case.

There is however, a broad field for dull matt glazes, applied to the proper kind of bodies. They should be used as a means of decoration only,and not as a protection to the tiles, for experience has shown that if a tile is not itself safe, glazing will not make it so.

CHAPTER XI.

STOCKING AND SHIPPING ROOFING TILES.

Drawing Kilns.—The removal of roofing tiles from the kilns is a simple operation incapable of much variation. At present, the work is wholly done by hand labor, and usually of the unskilled sort. The manner in which the tiles are set; i. e., with or without supports, or with or without strips, will of course vary the work in some of the minor details. Where supports are used, it becomes necessary to take the units down as the kiln is being emptied. To gain working room in the kiln, it is necessary to carry or wheel the blocks from the first five or six benches outside, and there pile them up. For the balance of the draw, the blocks can be stacked against the side walls, leaving a space through the center of the kiln for wheeling the ware out, and beginning the loading later on. Where tiles can be set without supports, the extra work of moving the kiln blocks at each burn is avoided, and the work of drawing can proceed rapidly from the start. The difference in time required to empty a kiln set with and without supports, is about as two is to one in favor of the latter method.

No matter how the tiles are set, they are taken down from the benches in handfuls of four to six tiles at a time, and placed on a wheelbarrow, such as is made for brick works. The tiles are placed on ends or sides as their forms may require. Spanish tiles, for instance, are loaded on end, two rows to a barrow. Interlocking and shingle tiles are for the most part placed on the side or edge, one row wide and two tiers deep, with common plastering laths between the tiers.

A wheelbarrow thus loaded with interlocking tiles will carry about thirty to forty tiles, and with plain Spanish tiles, about twice that number.

In kilns where the tiles are set self-supporting, it requires about one minute on the average to load a barrow, while in cases where the block system is used, it will require from two to three minutes for the same load. In either case, two men as a rule work on the same load. Part of the time, one man standing on lower benches passes the tiles down to the second man, or wheeler, who places them on the barrow; the balance of the time, when working on the lower benches, both men place the tile directly on the load.

It was observed at the plant of the National Roofing Tile Company, at Lima, Ohio, that portable four-wheeled trucks were being used to convey the tiles from the kiln. These trucks would hold from four to

six wheelbarrow loads each, and a permanent runway of plank had to be used for them. Unless on a level or down grade, two men were needed to move a load. As between the wheelbarrow and the truck methods, much can be said in favor of the former, at least for ordinary distances. The facility with which a wheelbarrow can be moved about from place to place, the narrow spaces needed in which to maneuver it, and the comparatively large loads that one man can move, all tend to make it a very convenient and satisfactory tool for the work.

With the building of larger plants it is quite possible that it may be found advantageous to use a conveyor system for the unloading of roofing tile kilns, such as is done in some brickyards at present, but such a provision would seem out of place on any plant now in existence.

Sorting or Grading the Ware.—The barrow loads of tiles are wheeled to a sorting table, or low bench, in the yard, where the wheeler leaves them, bringing an empty barrow away when he returns. The sorter has three or more wheelbarrows conveniently arranged about the table, upon which he places the tiles as he sorts them into firsts, seconds or thirds and into the various shades. As fast as a barrow is filled with tiles of one grade it is wheeled away by another man, and piled up in the car, stockhouse or yard, as the case may be.

A good sorter, under ordinary conditions, can grade tiles as fast as two wheelers can load and bring them to him from the kilns. In a few of the yards the tiles are wheeled from the kilns, and stocked at once on general stock piles by the wheelers, the sorting being done at a later period by the regular sorter. This method makes more handling of the tiles, and has no advantages in particular to justify its use.

The sorting or grading of roofing tiles on most of the yards is very poorly done. In some cases no further attention is paid to this feature than to throw out the obvious culls. Such a practice should be severely criticized, for tiles shipped after this kind of sorting are sure to prove unsatisfactory on a first-class roof, and are a detriment to the industry as a whole. The conditions in every plant at times are such that the temptation to ship everything that can by any possibility pass muster is very strong. Sometimes the demand for tiles has been above the supply. Sometimes, in a weak and struggling plant, the urgent need of money has brought about poor sorting, in order to get shipments on the way so as to be able to draw on the consignee earlier. The policy of high-grade sorting justifies its cost in the long run beyond any question.

The careful sorting of tiles into shades is a matter of far less importance than the grading as to soundness, freedom from warpage or structural defects. There is a widespread and well-founded demand at the present time for a liberal range of shades in one order. In fact, calls are not uncommon for a much greater variation than is produced in the normal product of a kiln of ware. Architects have gotten away from

the use of closely shaded colors, either in bricks or tiles, and it is not likely that the demand for close matching of shades will return, at least in this generation. Tiles, like bricks, when closely shaded prove monotonous in appearance, while a variegated roof or wall has a texture or character far more pleasing to the eye of a cultured observer.

Yarding or Storing Roofing Tiles.—Up to the present time the carrying of large stocks of roofing tiles has been for the most part unknown. Many of the plants in the past have for the greater part of the time been behind in filling their orders. In such cases the stock piles, if any, represent only seconds and culls.

While some of the plants have built large stock sheds, the larger number of them make no provision at all, except limited shed room for the trimmings. With a closer grading of the ware and larger outputs, it will probably become the practice to house all first grade ware at least. Where yarded in the open, the tiles soon become very dirty, and in the winter they freeze together in the piles, thus making shipments next to impossible.

The method of piling the stock in the open is quite clearly shown in the accompanying illustration, Figure No. 178, where both interlocking and Spanish tiles can be seen.

Interlocking tiles are generally stacked on edge, with plastering lath between to keep the tiles from rolling and the courses level. Boards are usually placed on the ground for the first course of tiles to rest upon, otherwise the superimposed load will sink them down into the dirt.

In Figure No. 179 can be seen the method of storing auger-made Spanish tiles. It will be observed that this company has provided a shed for the protection of its stock. The tiles are yarded by standing on end about four courses high, with lath or strips between.

The stocking of hip rolls and cresting is accomplished in much the same manner as for tiles. The larger sizes stand upon end, about four courses high. The smaller sizes that will not stand solidly are in some cases stocked in racks or bins, piling them up so that they cannot fall. Larger pieces, like finials and special ware, are in some cases stored on racks or shelves, but it is not uncommon to see them left standing about the yard, to become begrimed with soot and dust until they look like second-hand ware before they are shipped.

Packing and Shipping Roofing Tiles.—With very few exceptions the roofing tile manufacturers of this country ship practically all of their output to distant markets, thus entailing the loading of the ware into freight cars. On the ideal yard, the loading switch is depressed to a point where the floor of a car is at the stock-yard level. This is very important, because the tiles are in all cases wheeled from the yard into the car, and in those plants where the men are forced to wheel the

Fig. 178—Stock Yard Showing Manner of Piling. Chicago Heights Plant, Ludowici-Celadon Co.

Fig. 179—Storage Shed for Spanish Tiles. Cincinnati Roofing Tile & Terra Cotta Co., Cincinnati, Ohio.

tiles up inclined runways, smaller loads will surely be wheeled and the loading will prove more expensive.

In loading a car, the tiles are placed in the same position as for storing on the yard, i. e., the interlocking are packed on edge and the Spanish as a rule on end. The car loader begins by placing a row of tiles from side to side of the car at one end, leaving about a two inch space into which straw is packed tightly. In addition straw is wedged in at either end of each row to prevent lateral motion. Plastering lath are then placed on top of each row before the second or next one above is put in. When about four courses have been placed in the first row or tier, either straw or a lath frame is placed between the first and second rows as the latter is being filled. Both ends of the car are filled, until the open space between the doors is all that remains unfilled. Bracings are then put in across the space as in figure No. 180.

To prevent the piles from being knocked over by the jolts in transit, as a general rule only plain tiles of regular shape are packed in rows and tiers as described. All trimmings, such as finials, crestings and special pieces, are packed on top of the regular tiles, while small pieces, like small cut hip and valley tiles, and tower tiles, are frequently packed in barrels in order that they may not be broken or lost between the car and building at the unloading point.

Packing Material.—For the greater part, the packing material is either wheat or oat straw, preferably the latter on account of its softness. The ideal material, however, is the so called prairie or wire grass, so extensively used for packing bananas. This material has very great toughness and at the same time is very soft and pliable. It makes the work of packing easy. At some points, sawdust and shavings have been used; of the two, the latter is the better, though neither is satisfactory. The constant jarring of the car causes the sawdust or shavings to work down, leaving the upper courses loose, in which case many of the tiles will be broken.

In the loading of roofing tiles, it is usual to work a double crew, that is, the loading of the car is started simultaneously in each end. To properly carry out the work, there are required two packers, two helpers, two wheelers and one man at the stock pile assisting in loading the wheelbarrows. With the above number of men it is possible to load and pack a car in ten hours. Such a car would contain about seven thousand (about fifty-four squares) interlocking (French A pattern) tiles, and in addition the usual amount of cut work and trimmings to go with them.

Under favorable conditions the above figures are high, but are such as would obtain where the tiles must be wheeled up from the yard to the car level. Where a depressed loading track is used, these figures can be cut materially. If a liberal supply of packing is used it increases

the time of loading. In rough figures, the cost of loading, packing and bracing tiles will fall between fifteen and twenty-five cents a square.

Local Deliveries.—In plants like those at Detroit, Cincinnati and St. Louis, it is possible to deliver many orders by wagon haulage. In

Fig. 180—Car Loaded with Roofing Tiles, Showing Method of Bracing.

such cases the tiles are loaded in the wagon box or bed very much in the same manner as they would be loaded in cars, a very liberal supply of straw generally being used. However, the Cincinnati company, making a well vitrified tile, has delivered many hundreds of squares by wagon without the use of any straw whatever. The tiles (Spanish) were loaded by carrying the tiers as rows from end to end of the wagon, rather than across, with wooden strips between the upper and lower rows.

CHAPTER XII.

THE LOCATION AND DESIGN OF PLANTS FOR ROOFING TILE MANUFACTURE.

In considering the organization of a new roofing tile factory, the questions to be considered are: first, Where shall it be located? And second, How shall it be constructed?

LOCATION OF PLANTS.

Before considering the intimate questions of design at all, the engineer should first inquire into the fundamental or limiting questions on which success or failure will ultimately depend. These factors are:

First. Capital sufficient not only to build the plant in such a way as to take advantage of all possible economies in operation, but also to operate the plant during those trying months or years when a new concern is competing for a market and establishing a reputation.

Second. A suitable and sufficient supply of raw materials, including clays, fuel and water.

Third. An adequate supply of labor and facilities for housing the same (if not adjacent to a town).

Fourth. Proper shipping facilities.

Fifth. An adequate market within commercial reach.

It is not intended to list these items in the order of their relative importance. As a matter of fact, all are essential, and unless all of these qualifications can be met, the enterprise cannot hope to succeed. Discussing each in turn:

Capital.—Deficient capital is the cause in nine out of ten cases where clay-working enterprises fail. The conditions at one time permitted a plant to start with small beginnings, and work along with but little expenditure, gradually growing strong by turning the profits back into the business. The same is still true in a general sense, but the difference comes in what is now considered necessary to a small or modest start. In this day of combinations, the difficulties met by any new plant in breaking into the market are not to be minimized, and it is an absolute requirement that the new enterprise shall be able to produce wares of acceptable quality at as low cost as the big and powerful competitors who already have the business. If the plant has been under-capitalized, and is doing business at a high labor or fuel cost, to save cost in equipment or kilns, then its chances of keeping its head above water during the first year or two are very

poor. If the plant is new, modern, up-to-date, and saves labor and fuel at every turn, it has an excellent chance to succeed in spite of any competition, for its competitors will not for any long time cut prices below their own cost of production. The cost of production is thus the crucial matter with the new plant.

Fig. 181—General View of Plant of Huntington Roofing Tile Co., Huntington, W. Va.

Working capital is just as necessary as that which is tied up in equipment. No clay manufacturing industry can expect to start off with the production of high percentages of good saleable ware. The clay industry is peculiarly susceptible to little misadjustments and any and every stage of the process may give trouble in unforeseen ways. No other industry, except gold mining, has broken up so many cocksure novices, and mulcted so many investors. For these reasons, every plant is likely to run at a disadvantage for some weeks or months, possibly even a year or two, while conquering the difficulties of its material, and learning to give it the individual treatment necessary. During this period, the losses are usually irksome and hard to bear. Any firm that has put its all in its plant, and is living from hand to mouth during the probationary period, is in a bad way. In general, a clay manufacturing company should have a working capital ranging from fifty to one hundred per cent. of its plant-cost, to make its chance of success assured.

Raw Materials.—An adequate raw material supply is an undisputed *sine qua non* of success. Its importance cannot be overestimated, but in the past the error of investors has been in seeming to consider this item as being of itself sufficient to assure success. The facts are that clays suitable for the manufacture of most of the common clay products are abundant and well distributed. Their presence on a piece of land is so common a thing that of itself it does not scarcely constitute an asset. Of course, many special cases occur where a good clay bed

is an asset of value. But it is commoner by far to find that a company could establish itself on any one of a dozen or a hundred farms in a given district, and obtain from any of them an adequate clay supply. The limiting condition is found in the transportation facilities, or the labor supply, or the freight rates to market, etc.

The proper attitude of mind, therefore, on the part of the promoter of the plant is to *assure himself of the satisfactory qualities of the clays on some certain tract of land, of which the other factors of success are known in advance to be safe.* No clay property itself is good enough to justify putting a plant on it, unless the other qualities also support the proposition independently.

The quality of the clays needed for the roofing tile industry have been discussed at some length in Chapter III, and while it was shown that no clay unites all the good qualities, and that every material has some drawbacks, it was nevertheless shown that there was no great difficulty in deciding whether a clay's good points overweighed its faults.

The principal feature to be urged at this point is the necessity of making a careful and scientific study of this question before going deeper into the project.

The material should not only be thoroughly tested as to its physical and pyrochemical behavior, but the extent and uniformity of character of the deposit should also be carefully studied.

Instances are not uncommon where a fine outcrop of clay has pinched out or changed in quality and become worthless, almost within sight of the original opening.

In the selection of clays of the alluvial and glacial class for roofing tile purposes, even more precautions should be exercised than in shales. The variability in their conditions of deposition render their physical properties and chemical composition liable to constant or immediate changes in short distances or depths. Shales and fire clays are generally deposits of large superficial area, and change their character much less often or less rapidly than clays of glacial or alluvial origin.

A poorly designed or badly constructed plant can be gradually improved and made to answer its purposes, but if a plant is once located upon a poor or treacherous clay nothing can be done to rectify this trouble—it exists as a permanent handicap.

Cases are on record of plants having been located upon materials entirely unfit for or unsuited to the manufacture of roofing tile. Whether the cause or reason was a false idea of economy in not expending the money to make a thorough and complete survey and test before locating cannot be stated. Strange as it may seem, otherwise shrewd business men, for the sake of saving a few hundred dollars spent in properly testing and exploiting a clay property, will risk thousands of dollars in building a plant on materials they do not know to be good. While a few plants established upon such unsatisfactory clays have continued

to make tiles, by dint of abundant capital and good business management, many others have failed outright after expending large sums of money in trying to overcome their original mistakes.

On the question of fuel supply there are two points of view, viz., quality and price. The ideal fuel as to quality is natural gas. Very few plants in the past, however, have been so fortunate as to be within reach of this perfect fuel, nor is it to be anticipated that those in the gas belts will long be able to afford it. It should be reserved for better uses. Crude oil is also used to some small extent in the industry, but

Fig. 182—General View of Plant of the United States Roofing Tile Company, Parkersburg, West Virginia.

its supply is also limited and not likely to remain long available for such uses. Where available, crude oil is scarcely second to natural gas in the quality of work it can do and in its fuel value, but it is very much inferior in convenience and cleanliness. It is ill smelling, dirty to handle, and requires much adjustment at the burners.

One plant is so situated that pitch pine is available as the fuel supply, but such conditions are so rare that they do not call for consideration here.

Under existing conditions the greater part of the tiles produced are burned by coal in furnaces directly attached to or a part of the kiln. Unquestionably coal will be, in the future even more than at present, the fuel used. Hence in selecting a new site for a roofing tile plant it becomes very necessary to investigate the conditions of supply as well as the price and calorific power of the coal.

The establishment of a roofing tile plant in a new district, where coal is brought in from long distances, and therefore is high in price, will be doubtful unless it can be shown that the handicap on the coal

is offset by the saving of freight on the shipment of the finished product to the market. Tiles go at higher rates than coal, and will weigh several times as much as the coal required to make them, hence it may be a real economy to ship the coal; but these conditions must be carefully studied, and nothing taken for granted, before establishing a plant.

The quality of the coal also comes into consideration. Some coals cannot be used for clay product manufacture on account of low calorific power, high sulphur, bad clinkering properties, lack of flame, too much flame, etc. Roofing tiles require relatively low temperatures, and hence permit the use of some coals which would be ruled out for pottery or fire clay goods.

The water supply is a matter often overlooked, but of vital importance. Roofing tiles do not require the pure supply that is important in white ware industries, but the abundance and the nature and amount of its contained solids is important. It should be a good boiler water. If not, the cost of a treating plant must be added to the equipment, and the cost of chemicals, labor and supervision must be allowed for in running expense. A clay plant uses water to at least twenty-five per cent. of the weight of its output daily, and often more, so that many tons of water per day must be provided.

Labor.—A considerable amount of skilled labor will be required for the various departments. The skilled labor will ordinarily have to be imported to the vicinity of a new plant. Modelers, moldmakers, pressers, mitre cutters, etc., cannot be created or trained rapidly, and they are usually secured around terra cotta plants and potteries or other roofing tile plants and brought to the new works. The task of welding the heterogeneous mass of skilled workmen into a compact, organized, co-operative body, where each is willing to do his share for the common good, is one of the burdens of the manager. It involves selection, culling out mischief makers, promoting men of good character, teaching local men to fill vacancies, smoothing down jealousies, etc.

But aside from this most interesting phase, the social side of the situation must be considered. Good men cannot be secured, or at least kept long, under conditions involving poor food, poor quarters, poor schools, bad moral conditions, unfit surroundings for their families, etc. If a new company is established in the country, it means that housing, stores, churches and social amusements must be provided if a good class of men is to be attracted.

The actual conditions of labor in a roofing tile plant are favorable compared to most of the structural material industries. The unit weights handled are not large, and men are not under the heavy physical strain involved in brick or sewer pipe manufacture. The cars are lighter and easier handled, the kilns are smaller, the firing period shorter, the firing not so excessive, etc. These conditions all make it easier to procure

Fig. 183—General View of the Plant of the Western Roofing Tile Company (Since Taken over by the Ludowici-Celadon Roofing Tile Co.), at Coffeyville, Kansas.

and retain native American labor. The brick industry has very largely followed the large metallurgical industries in using gangs of imported laborers from southern and eastern Europe, but it is hoped that the roofing tile business may be saved for our own people.

Transportation Facilities.—A railroad is essential. Considering the fact that at least ninety-five per cent. of all roofing tiles made in this country are shipped by rail, it is very important that this point be well looked into before selecting a final location. Outside of locating on a trunk line or one of its tributaries, or better still, at a junction point where competing lines are accessible, it makes very little difference as to the exact locality for the plant. There are so few existing plants, it becomes necessary to ship the product to great distances in any case.

The roofing tile plants of Ohio are shipping their products from coast to coast, and from the gulf to our northern frontier. Of course, a location near a large market or city is to be preferred over one at a greater distance, provided other conditions are equal.

Market.—The greatest market for roofing tiles at present is in the larger cities, in all sections of the United States. Many tiles, however, are used in the smaller towns and county seats. The chief competitor of tiles so far has been slate. When the time comes that roofing tile plants are more numerously distributed over the country, so that shorter hauls and less freight will be attached to each tile roof, then will the tile market expand and fill every field, even to country dwellings, where slate or shingles now prevail. At present there are sections of the United States where tiles are used more extensively than in others, and this can be charged directly to the cost of tile delivery to the backward sections. The rarity of a tile roof is not due to any popular dislike of it, nor to any objectionable features. They would be universally used but for the excessive cost, which has to be made high to cover the long average haul by rail from factory to consumer. Hence it is firmly believed that the chances for success of a roofing tile plant, as far as the market is concerned, are practically as good at one point as another, provided the wealth of the communities are approximately equal. There are of course poor districts, where no large market for anything exists. But, wherever people are prosperous, there is room for this industry. There are vast areas of the United States that are as yet untouched by the roofing tile industry, and such points should make exceptionally fertile fields for wise and conservative promotion in this line. The great South and Southwest seem especially favorable.

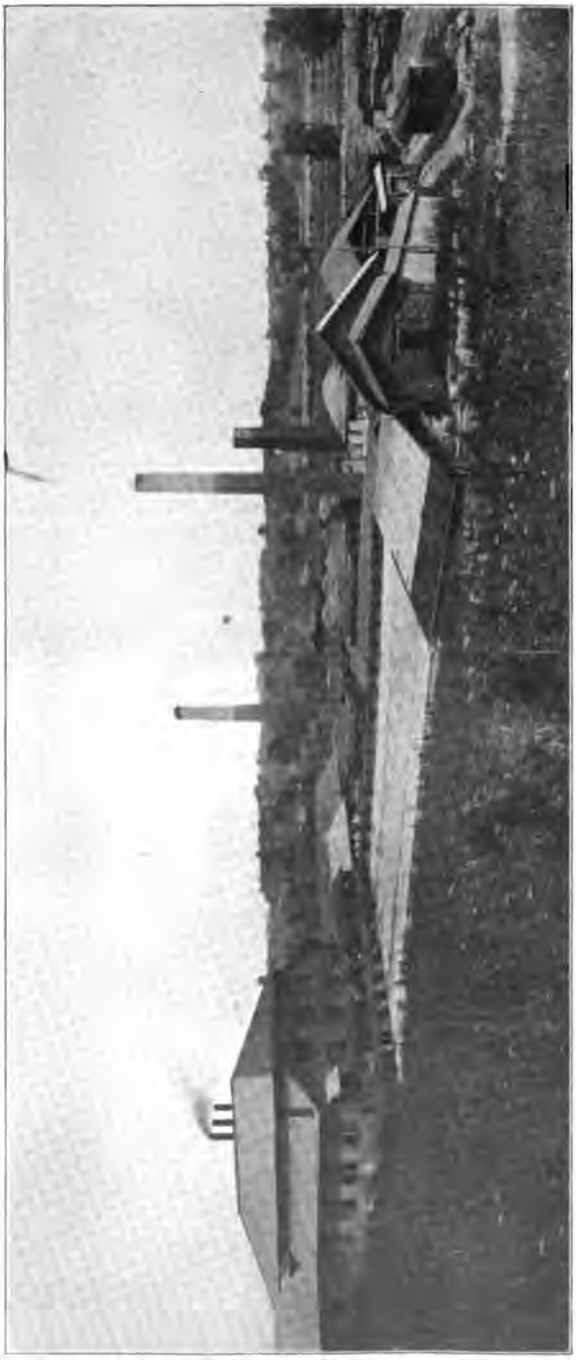


Fig. 184—General View of the Plant of the Ludowici-Celadon Co., at New Lexington, Ohio.

PLANT DESIGN.

Having duly considered these essential conditions of location, the more intimate and practical questions of plant design must be taken up. In designing a plant for the manufacture of roofing tiles, the ceramic engineer is confronted with a problem of somewhat greater intricacy than in the design of a plant for the manufacture of building bricks, paving bricks or sewer pipes and hollow wares, for two reasons: *First,* the ware is of thin cross-section, which necessitates the use of more care in the preparation of the clay, and in the handling throughout the various stages of its manufacture. *Second,* The problem involves manufacturing not one size and shape of product, as in brick works, or a dozen or two as in pipe works, but scores. No two orders are apt to need the same equipment of extras and trimmings, and filling each order causes a change in the material passing through the plant. Many orders are for parts never called for before, and not likely to be called for again, and in this sense, any order is a problem to be solved. Of course, the main roofing material is confined to from three to six varieties in most plants, in some even to one or two, but the trimmings are capable of endless variation. The plant design must therefore provide for elasticity in the kind of output.

In other respects the factors to be considered in the design of the plant are not dissimilar from those of other clay plants.

The Influence of the Type of the Clay.—The design of the plant will be governed very largely by the raw material selected, viz.: whether a shale or a plastic clay. In the case of a shale, the grinding facilities will have to be much heavier, the screening will be more carefully done, and generally to a finer size; there is less necessity of storing large quantities of dry clay in the summer for use in the winter, so that stock sheds may be reduced or cut out; it may be necessary to provide means for the storing or aging of the clay after pugging to develop plasticity enough, etc. In the case of a soft plastic clay as the base of supply, aging may not be required, but large storage capacity for dry material for winter use will be necessary.

Influence of the Kind of Tiles.—In addition to the type of the clay, the form of the tiles will enter very largely into the proper design of the plant, because it involves the selection of the manufacturing machinery. A shingle and Spanish tile plant would be equipped with auger machines of large size and high power, for expressing the small narrow ribbons of clay at a relatively stiff temper. Their outfit of presses would be confined to trimmings presses.

An interlocking plant on the other hand would use a small light auger machine for making blanks, and an array of heavy pentagon presses.

Fig. 185—General View of the Plant of the Murray Roofing Tile Company, at Cloverport, Kentucky.

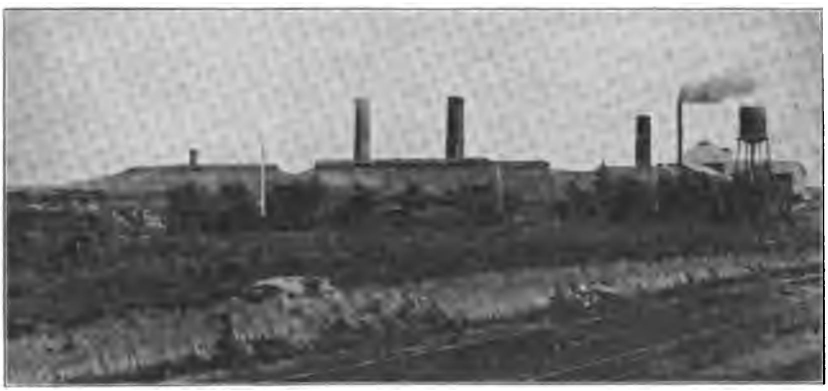


Fig. 186—General View of the Plant of the Ludowici-Celadon Roofing Tile Company, at Chicago Heights, Illinois.

Existing Plants no Criterion.—In a study of the existing roofing tile plants in this country, it is very noticeable that little engineering has been used in their design. For the most part, they are the outgrowths of very small beginnings, and have grown by accretion, additions being made from time to time at the points of least resistance, until many of them are a conglomerate, very badly arranged for future growth or present economical operation.

The explanation of this state of affairs can be traced in many instances to the fact that these same plants were established upon the wreck of some bankrupt brick or drain tile plant, which in the nature of the case would be ill adapted to the purpose. Successful plants have in some instances been developed upon such beginnings; success under such conditions reflects all the more credit upon the management, but it emphasizes the fact that if these poorly arranged plants have been able to prove profitable, how much more so would a properly designed plant have been.

Design of Plant to Meet Given Conditions.—Figure 187 inserted at page 463 is submitted as an illustration of the way in which this problem may be met. It is necessarily designed to meet hypothetical conditions, but these have been made as probable as possible. The problem selected was to design a "combination" plant; i. e., one which could produce any of the standard shapes at will. It could run on shingle tiles, Spanish tiles and interlocking tiles and make the necessary trimmings for each. For the most part, such plants are one-press plants, Hence, in this design, the object in view has been to use as little machinery for the output as possible, but to operate each machine to its full capacity all of the time, and in addition so to design the plant that its output could be increased in the future with the least expense, and at the same time without interfering with the original lay-out and operation of the portion already built.

Raw Material.—The raw material has been assumed to be a soft alluvial clay, of which thirty to thirty-five tons per day would be required.

Winning.—This daily tonnage would no doubt prove too small for the employment of a steam shovel. Hence clay gatherers similar to that illustrated in Chapter IV would be used, in connection with a car and cable haulage system to bring the gathered clay from the field to the stock shed. It is not economical to use the clay gatherer for transportation of the clays for any but the shortest possible distances. The clay, after being dumped into the cars, would be quickly transported from the field to the disintegrating machinery, or dumped into the storage shed for use during the winter months.

Storage.—The storage shed would be equipped with overhead track in the center, giving ten to fifteen feet dumping room below.

Under the center of the floor, extending from end to end of the shed, a belt conveyor would be installed. This would be covered by a floor of short pieces of plank, easily removable, so that the opening from the clay pile to the belt could always be kept close up to the foot of the pile, so that gravity would do most of the work of getting it onto the belt. One man in the stock house could feed the clay fast enough, and with very little shoveling. The conveyor would deliver at the foot of a vertical cup elevator, which in turn would deliver it to the grinding machinery.

Grinding.—For this purpose differential disintegrating rolls would be used, consisting of a relatively large, low-speed roll, against which would operate a small high-spe d roll. This first pair of rolls would not seek to grind the materials very fine. The action on the clay consists not only in crushing, but in shredding the caked flakes which have been crushed. The clay, after passing this pair of rolls, would drop into a second pair of large, rather low-speed rolls, which would carry the crushing to a much finer point, and deliver the product in a fairly uniform condition. From the second rolls the clay would drop into a pug mill. Should the clay be too dry, water would be added at this point. The clay, after passing through this pug mill, would drop upon a third set of crushing rolls, set extremely close together in order to crush the remaining hard particles. After issuing from these rolls, the clay would enter a combined pug-auger machine.

Forming the Ware.—The die of the auger machine would produce a bar of any desired shape, either for tiles or for blanks. Up to the auger machine the machinery is designed to work continuously. Since the plant is to be of the combination type, and not of sufficient capacity to use a double set of machinery, it would be necessary to operate the auger machine on various tiles or blanks, changing the die from time to time.

For the manufacture of interlocking tiles the plant would be equipped with one pentagon press, which would require in the neighborhood of six thousand blanks per day. With a good auger machine this number of blanks could be run in one-third of a day. Thus in order to run the auger continuously at proper speed, it would furnish the interlocking blanks three times as fast as necessary, and a storage room (so marked) for blanks would be necessary. By the use of this storage it becomes possible in two days to gain enough blanks in storage to keep the press busy the balance of the week. The bar, upon issuing from the auger machine, would be cut into blanks of the proper length by a simple reel cutter, and conveyed by the separating belt to the press and storage room. The press would be fed direct from the belt on the two days while blanks were being run, and the excess blanks not used by the press would be stored in the blank room.

At the end of the second day's run on interlocking blanks, the die and cutting table for either shingle or Spanish tiles would be substi-

tuted, and the machine would operate for the following three days on either of the latter shapes. In the case of Spanish tiles, they would be placed three deep on pallets carried by the Spanish table, and thence to the dryer cars. These cars would be transferred by the track back of the storage room, as indicated in the design. As each car received its load, it would move forward to the transfer track in front of the dryer, and thence to the proper tunnel. In the manufacture of the shingle tiles the operation would be the same, except that the Spanish cutting table would not be used, and the tiles would be taken direct from the off-bearing belt and placed at once on the dryer cars.

On the sixth or last day of the week the shingle or Spanish tile die and cutting table would be removed, and others substituted for the manufacture of special shapes and blanks for the trimmings press. In addition, it would be necessary to prepare the clay for use in the terra cotta room where the hand pressing and modeling is carried on. This clay would be conveyed by a belt conveyor direct to this room, where it would be stored in the bins indicated, and blanketed to keep it workable for the ensuing week. This clay is run at a different and softer temper than the clay used by the tile machines.

By the above scheme it is possible to operate the plant with one string of machinery and one crew of men and keep each machine working to its full capacity all of the time, thereby securing the greatest efficiency. There would be some handling of clay a second time in the interlocking department, and while it would be possible to have a separate and smaller auger machine operating exclusively and continuously on interlocking tile blanks, it would not be as economical and satisfactory as the plan suggested. It would not only call for an increased investment, but would require a considerable extra expenditure of power and more or less of one man's attention. In addition, the machine would have to be operated only partly filled with clay, thus producing a weak blank. In the plan proposed, if the future expansion of the plant required the installation of more presses, it would then become practical to install a second auger machine, using one expressly for blanks and the others for shingle and Spanish tiles.

For the return of scrap clay it will be noted that a belt conveyor has been indicated beneath the floor extending from the terra cotta room along behind the presses, past the cutting tables, to the auger machine. This scrap clay would be elevated at this point and passed only through the third set of rolls. This clay having been previously prepared would not need to pass through the entire string of preparing machines a second time after the manner of the raw material from the field, but would be sufficiently distributed by one pair of rolls and the pug mill of the auger machine.

Proposed Output.—The output per week for the machinery provided for in the above scheme, when operated as suggested, would be about as follows:

The interlocking or pentagon press would make in a week's run under ordinary conditions, about thirty thousand tiles. The auger machine would in three days' run turn out thirty thousand Spanish tiles or thirty-six thousand shingle tiles. On the sixth day, the auger machine after running sufficient soft clay to supply the terra cotta room for a week's work, and the necessary blanks for the trimmings press, could in addition make from one thousand to three thousand feet of bell-shaped hip rolls, or their equivalent in some other ware.

The trimmings press would work continuously, and in a week's run would make from twelve hundred to three thousand feet of cresting, or large hip rolls, the amount depending on the size.

The ware from the terra cotta room and the hand press, owing to its varied shape and character, would be hard to estimate, but would average about five tons per week.

Dies and Moulds.—For the greater part, the dies and moulds for this plant would be made of plaster. In order to have the point at which they would be made accessible, a space (marked plaster room) has been set aside in the corner of the terra cotta room, convenient to the presses and for the terra cotta moulds as well. This room would be furnished with a double-screw press, benches, sinks and water fixtures and other necessary equipment for plaster work. In a plant of the proposed size, one man would make all the necessary dies and moulds. In larger plants, a die-and-mould maker would have to be provided for each department of the work.

Dryer.—The dryer for this plant would consist of six double-track tunnels, one hundred feet long, operating on heat derived from the products of combustion emitted from boilers and kilns after passing them through regenerative stoves, and heat from the cooling o the kiln except when it was working on the continuous plan. When working as a continuous kiln, there would be no available heat for the dryer from the combustion products of the kiln.

In addition to these sources there would be added a set of steam coils using the exhaust of the engines and pumps. This last source of heat, with the addition of live steam, could be used in starting the dryer after a shut-down, or at times when the supply of waste heat from the kilns might be lacking or inadequate.

To operate this dryer, and to furnish a perfect draft for the kilns and boilers, there would be required two suction fans. One would draw the combustion gases from boilers and kilns through one of the regenerative stoves, and discharge them into the open air. In the meantime, the dryer fan would be drawing the fresh outside air through the other

stove, where it would become heated to the necessary degree for drying, and then forcing it through the various tunnels of the dryer. A third fan might be necessary to exhaust the moisture-laden, cool air from the other end of the dryer.

Dryer Equipment.—Assuming that the clay to be used would dry safely in the form of roofing tiles in twenty-four hours, twelve thousand pallets would be required to handle the output of the pentagon press for a two days' run. The cars necessary to hold this output would be about sixty in number, which would fill three dryer tunnels or six tracks.

For the Spanish tiles, produced on a two days' run, there will be needed seventy-five hundred pallets, three tiles being placed on each pallet. The cars necessary to care for the two days' output would amount to forty, filling four tracks or two tunnels of the dryer.

As stated before, the dryer was to have six tunnels, and as five of them have been used to care for the Spanish and interlocking tiles, there still remains one tunnel, holding twenty cars, for the special ware like cresting, terra cotta, and other shapes.

In addition to the pallets required to care for the Spanish and interlocking tiles, there would be needed thirty thousand pallets for the shingle tiles, and about five thousand special pallets, for eave and ridge tiles and other patterns.

It would not be necessary to have an increased car or dryer capacity to care for the shingle tiles, from the fact that the shingle tiles would replace an equivalent amount of Spanish tiles, hence, the same cars and drying tunnels would be used for each pattern.

In addition to the regular dryer there would be needed a small rack dryer in the corners of the terra cotta room, for the drying of large and intricate terra cotta finials and special shapes.

The heat necessary for this dryer could be derived from the same source as the larger dryer. An underground duct carrying the heat from the main heat flue of the large dryer to the proper point of delivery in the small drying room, or a small steam coil fed with exhaust steam from the pump, electric light engines or other minor supply might be profitably used.

Kilns.—Up to this point, but little departure has been made from the usual everyday practice, save in the matter of the heat supply for the dryer. In the matter of the kiln design some radical changes, which would make the plant more efficient and economical to operate, are recommended:

First. The kiln should be of the continuous type, the construction, however, permitting operation as a series of periodic units if desired

Second. The kiln should be operated with producer gas as the

fuel, except when fired on the periodic plan, when coal, fired in furnaces attached to each chamber, would be used, at least in part.

Third. The draft necessary to operate the kiln would be by suction fan, rather than by stack.

Fourth. The heat from cooling kilns would be partly used to preheat the chambers of ware in advance of the fire, and partly to preheat the air for combustion, as is customary.

Taking up the first point, the reason for the selection of a continuous kiln is the very great fuel economy, which runs from one-third to one-fifth of the consumption in good periodic kilns. The first cost of the continuous kiln may be somewhat higher than that of an equivalent kiln capacity in favorably sized periodic units. The difference in this respect should not be great, however. The kiln is designed so that it can be operated either way, but it would be most efficient when operated as a continuous one. The firing, when on the periodic plan, would take place in the furnaces at each corner of the chamber as shown. In case these furnaces did not furnish ample heat, some top firing could be resorted to, or temporary furnaces might be installed in each wicket.

While it is questionable whether the use of producer gas would be materially different in cost from burning coal direct, there are many points in its favor. Wyer[1] gives some of them as follows:

First. With regenerative appliances an unlimited intensity may be obtained. *Second.* It may be produced from the cheaper grades of fuel, and still make more available heat than is possible with the costliest fuel used on the ordinary grate. *Third.* No more skilled labor is required than with grates, the tendency being to decrease this. *Fourth.* Centralization of furnaces is obtained, thereby making it easier to handle the fuel by mechanical means. *Fifth.* Elimination of clinkering in the kiln, thereby decreasing the heat losses and wear on the kiln. *Sixth.* Steady maintenance of a uniform temperature. *Seventh.* More uniform burning. *Eighth.* Better combustion. *Ninth.* The mildness of the gas flames will insure the best results for the ceramic product under treatment.

These statements of advantages are mainly made from the standpoint of the mere production of temperature by the combustion of the gas. They do not look at the question from the standpoint of the chemical effects of the heat on the clay, nor from a deep knowledge of what the chemical conditions in clay firing actually are. The second, third, fourth, fifth and eighth points are of greater weight than the first, sixth, seventh and ninth. The intensity of temperature which it is possible to gain by producer gas is in no sense an advantage in low-fired wares like roofing tiles, nor is the indisputable ability to maintain

[1]Wyer, S. S. Gas Producers and Producer Gas, p. 201.

uniform temperatures hour after hour necessarily an advantage. Uniform burning may very easily require alternations of higher and lower temperatures, which are naturally obtained in coal firing, and not so easily where the fuel is controlled by a valve. Also, producer gas is intensely reducing and if not handled well will blacken the wares worse, rather than less, than coal firing.

There are also some other factors which must be considered.

Producer gas from bituminous coal is loaded with vapors of tar, which carries a not unimportant part of the total calorific power of the coal, and which will condense out if cooled below about 200°. This tar is thus lost so far as its heat value is concerned, and is worse than lost, for it fills up flues and pipes, causes valves to stick, and has to be removed generally at considerable cost. If removed by washing, so as to be recovered and sold, the tar has a ready value, and makes up for the heat value it has abstracted, but the gas is now much reduced, and will no longer ignite except in a red-hot fire box, and burning conditions are made much more troublesome by the gas easily going out with slight changes of pressure, etc.

Producer gas, washed or unwashed, has not yet been used with satisfaction in periodic kilns on account of the fireplaces being cold in the start. On continuous kilns, the ease of application is very greatly enhanced, and beyond the disposition of the tar but little trouble is met.

While producer gas has not been employed in this country for the burning of roofing tiles, it is firmly believed that when it becomes better known it will find a ready and open field in the tile industry.

The use of mechanical draft has already passed the experimental stage in the roofing tile industry of this country. The excellent results obtained by its use leave little if any argument against it. It is positive at all times. It is possible by the use of draft gauges to systematize the burning to a far greater degree of certainty than is possible by the variable draft of a chimney. In the design shown, the mechanical draft is attached to the boilers of the plant also, thereby extending its advantages to the power and light department, in addition to the utilization of the heat otherwise lost from the boiler furnaces. It is estimated that in this latter point alone is a sufficient saving to cover the cost of the operation of the mechanical draft equipment.

In the plan suggested, owing to the use of the producer gas, it becomes necessary to utilize a large amount of the heat from the cooling wares to obtain the proper combustion. Any heat from this source in addition to what is needed for combustion would be drawn forward and turned into the chambers ahead of the fire, thereby preparing them for contact with the combustion gases, without risk of any deposit of dew, which in ordinary continuous kiln practice frequently gives rise

to scumming. The gases of combustion after passing through as many chambers as was found economical would enter the smoke duct and pass on to the fan, and thence through the fan to the open air.

Kiln Capacity Required.—Owing to the variations in the rate at which different clays can be burned and cooled, it is impossible to furnish exact sizes of kiln chambers except by making arbitrary assumptions. Each kiln or chamber should hold a single day's output of the plant, and it will be assumed that the clay can be burned safely in seventy-two to eighty hours and that a chamber can be cooled in the succeeding forty-eight hours. Then to care for the output of the plant as already listed, the chambers should be approximately fourteen feet by eighteen feet in the clear, not counting bag space. A chamber of this size, where kiln blocks are used for the setting, would hold approximately nine thousand five hundred Spanish tiles, or one day's run less the dryer loss and setting breakage. Thus to care for the Spanish tiles it would need three such chambers per week, each alternating with a chamber for interlocking tiles. The same sized chamber would hold a two days' run of interlocking tiles. With the pentagon press operating six days of each week, three chambers would be needed to hold the weekly interlocking tile output.

In order to care for the special work from the trimmings press, hand press, and terra cotta room, it would be necessary to provide two more chambers. While the last two chambers would not be used exclusively for the special ware, their capacity would be needed to provide for the crowding out of the regular tiles by the trimmings or terra cotta set in each chamber from day to day. The burning cycle for each kiln would be: setting, one day; burning, three to three and one-half days; drawing, one day; total, seven to eight days. But to allow for the irregularities introduced by Sundays and holidays, and the exigencies of labor shortages, unfavorable weather, cleaning and repairs, etc., at least one extra day should be allowed per cycle in computing the monthly kiln schedule, and this would call for at least nine kilns for the plant.

The necessary equipment for each burning would include fire clay kiln blocks or supports sufficient to equip each kiln. For the chambers in which the Spanish tiles are set, there would be required two thousand blocks two and one-half by eleven by fifteen inches. The chambers to be used for interlocking tiles would need approximately twelve hundred blocks two and one-half by eleven by eleven inches and eleven hundred blocks two and one-half by eleven by fifteen inches.

The shingle tiles would be set with straps, as described in Chapter VII, and could therefore use the same blocks and chambers as used for the Spanish tiles.

Power Plant.—The power required for the machinery in the plant just described would amount approximately to 130 horse power. Hence,

in order to allow for the addition of a second auger machine and several pentagon presses, it would be advisable to install a 200 horse power engine in the beginning. This engine should be of Corliss or equivalent grade and of high efficiency.

The steam necessary to operate the plant could be furnished by two 150 horse power boilers of the tubular type, but there should be installed a third boiler, in order that one boiler could be shut down for cleaning and necessary repairs at any time. Steam for the two fan engines would also have to be furnished from the boiler plant.

The exhaust from the four engines and two pumps would partly be passed through a feed-water heater and, with the remainder not so needed, would then be sent to the steam coils which would be a part of the equipment for the heater for the dryer.

In addition to the regular power there would be installed a 50 horse power engine for driving a dynamo, to furnish light and power for distant machinery, such as pumps, glaze mills, or machine shop tools. The dynamo would be so located that in case of the breakdown of the small engine, a belt drive could be used from the main line shaft as indicated.

The coal necessary for the boilers would be delivered on a railroad spur passing the boiler room, and would then have to be shoveled into the coal storage bins behind the boilers.

For general shop work and repairs about the plant a room has been set aside in the boiler room (marked machine shop). In this room there would be a drill press, lathe, shaper, emery wheels, small forge and blacksmith tools, tools for pipe work, etc., with storage room for chain hoists, jack screws, bars and other tools essential about a plant of this nature.

Future Expansion of the Plant.—That the plant has been so designed as to be very easily enlarged can be readily seen.

In the power department space has been left for a fourth boiler and an engine has been installed of greater capacity than will be needed at the first. In the clay-preparing department the rolls, disintegrator and pug mill originally installed will care for twice the initial output. As it became necessary to increase the manufacturing capacity with more pentagon presses, the terra cotta room, its dryer and the plaster room could be moved back far enough to allow for the additional presses. The end of the building in which the terra cotta room is located would be of temporary construction, so that the extension of the building would be a simple problem.

The position of the trimmings press could then be changed further back, so that the regular presses could be located properly. The dryer could be extended by the addition of as many tunnels as necessary, without any change whatever except the moving over of the return

car track on that side of the dryer. The fans and ducts for both mechanical draft and the dryer would be installed sufficiently large to care for any reasonable growth.

The enlargement of the kiln capacity would require only the building of more chambers onto the end of the original kiln.

The fuel gas plant would consist of two producers, only one of which would be required at a time, the additional one being held in reserve in case of trouble with the one under fire. Hence, in case of the number of kiln chambers being increased, both producers could be put into commission and a third one built for emergencies. The loading switch could very easily be extended to care for the increased output.

Figure 188, inserted to face this page, is a design for the ground plan of the hypothetical Roofing Tile plant, which serves as the basis of the discussion on plant design, page 453–462. The kiln plant is necessarily much shortened to get it within the available space. The scale of the drawing, after reproduction by the engraver, is approximately 17.2 feet per inch.

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Geological Survey of Ohio, Bulletin Eleven. Figure 187.
Ground Plan Design for a Roofing Tile Plant.

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